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NORTH ATLANTIC OMEGA NAVIGATION SYSTEM VALIDATION.

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16. Abstract

The OMEGA Navigation System provides a worldwide enroute positioning capability from eight transmitting stations. Although the operational transmitting stations now provide useful navigation signals, the system will not be declared fully operational until the validation program is completed in 1985. The validation program is being accomplished on a regional basis through a measurement process conducted by the U.S. Coast Guard. The North Atlantic is the second region to be validated.

The data base for the North Atlantic Validation consisted of LOP Phase measurements from 36 stations of the OMEGA Navigation System Operations Detail (ONSOL) worldwide monitor network and signal amplitude measurements, both ground and airborne, throughout the area collected by the Naval Ocean Systems Center (NOSC). These data were supplemented with integrated OMEGA/Satellite shipboard measurements and numerous OMEGA measurements and observations from ship and aircraft users, both civilian and military, from several countries.

The analysis results indicate that with the exception of a few small areas, OMEGA provides at least three station coverage at 10.2 kHz. The 10.2 kHz voids are well covered at 13.6 kHz except for the extreme western part of the Gulf of Mexico during summer day. The predictable and repeatable accuracy of the 2-4 nm (2-drms) for OMEGA is met in the North Atlantic where signal coverage is provided.

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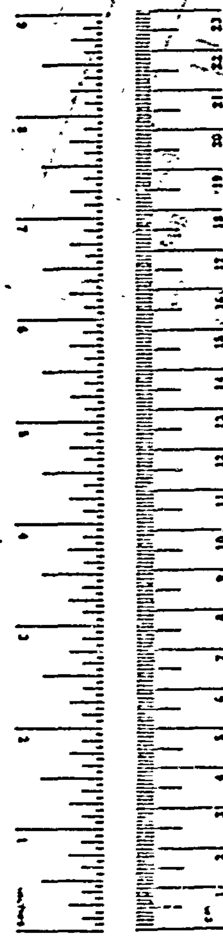
PREFACE

This report presents the results of the validation of the OMEGA Navigation System in the North Atlantic. The coverage being provided at 10.2 kHz and 13.6 kHz is described and maps showing recommended LOPs by geographical area are presented. Also included are studies of phase difference bias errors, effects of Sudden Ionospheric Disturbances (SIDs) on position fix accuracy and an evaluation of a variety of operational data.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

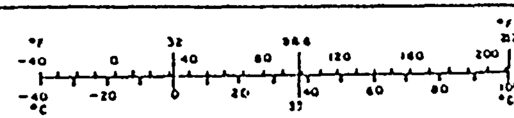


TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

EXECUTIVE SUMMARY

An assessment of the coverage and accuracy being provided by the OMEGA Navigation System in the North Atlantic (0°-70° N. Latitude, 15° E.-100° W. Longitude) has been completed. The data base for this validation consists of long-term data from the U.S. Coast Guard fixed monitor sites, short-term data collected specifically for the North Atlantic region by the Naval Ocean Systems Center (NOSC) cooperatively with the Federal Aviation Administration Technical Center (FAATC) for the U.S. Coast Guard, OMEGA/Satellite shipboard data and data provided by various users.

The OMEGA Navigation System characteristics as specified in the proposed Federal Radionavigation Plan (5) are:

- 99% system availability
- 2-4 nm (2-drms) predictable and repeatable accuracy

Also, the use of the OMEGA Navigation System generally requires the availability of signals from three or more stations.

The results of this regional validation show that:

- Coverage: The system meets the three station coverage requirements at 10.2 kHz except in two small areas in the extreme northeastern sector of the North Atlantic and in the western part of the Gulf of Mexico during summer day, and the near field zone of the Liberia (B) station during daytime, both summer and winter. With the exception of the western part of the Gulf of Mexico 13.6 kHz signals provide coverage in all of the areas not covered by 10.2 kHz signals.
- Accuracy: The predictable accuracy of the OMEGA system is 0.8 nm during summer day and 2.4 nm during winter night when using the most accurate LOP combinations. Similarly, the repeatable error, expressed in 2-drms, is 1.4 nm during summer day and 2.2 nm during winter night.

- <u>COVERAGE ASSESSMENT</u>

The coverage being provided by OMEGA in the North Atlantic was assessed based on the following criteria:

- Areas likely to be affected by near-field phenomena (i.e. areas close (∿ 1 Mm) to transmitting stations) were rejected.
- Areas likely to be affected by modal interference phenomena were rejected.

- **Areas with Signal-to-Noise Ratio (SNR) < -20 dB in a 100 Hz bandwidth were rejected**

The modal and near-field areas are functions of the intrinsic signal properties and therefore result in a "hard" boundary in terms of coverage whereas the SNR threshold is a function of receiver design and is considered a "soft" boundary. The SNR (100 Hz) criteria of -20dB was originally selected based on the design of marine receivers in existence at the time (1974). This SNR which occurs at the threshold of phase tracking will vary with different types of receivers. However, because -20 dB was used for the theoretical predictions of OMEGA 10.2 kHz coverage, it has been retained for the validation process.

Coverage Overview

The following summarizes the 10.2 kHz signal coverage being provided in the North Atlantic by the OMEGA transmitting stations.

Norway (A): The Norway 10.2 kHz signal is accessible to most of the North Atlantic with the exception of the western part of the Gulf of Mexico and the Gulf of Guinea at all times and a small portion of Baffin Bay during summer day.

Liberia (B): The 10.2 kHz signal from Liberia covers most of the North Atlantic during the day except for a small region of the northeast coast of the U.S. and Nova Scotia during the summer. At night, for both summer and winter, the 10.2 kHz Liberian signal is usable only northeastward of a (great circle) line from Dakar to Frobisher Bay.

Hawaii (C): During the day, the Hawaii 10.2 kHz signal is excluded in the following regions: 1) east of 40° W. Longitude and north of 30° N. Latitude during the summer and 2) east of 25° W. Longitude and North of 15° N. Latitude during the winter, except for a small region in the Norwegian Sea. At night, both summer and winter, the Hawaii signal is excluded east of a line from southeastern Greenland to Morocco except for a small region in the Norwegian Sea.

North Dakota (D): The North Dakota 10.2 kHz signal covers all points in the North Atlantic, day and night, except for a small portion in the extreme northeastern Atlantic during summer day.

La Reunion (E): 10.2 kHz signals from La Reunion are mostly "long-path" to points in the North Atlantic, especially during daytime over the short-path. In those regions where the long-path signal is blocked by the low conductivity in Greenland, the nighttime signals are modally disturbed and the daytime signals are highly attenuated.

Argentina (F): Daytime 10.2 kHz signals from Argentina are accessible to points in the North Atlantic up to 50° N. Latitude during the summer and 60° N. Latitude during the winter. The western part of the Gulf of Mexico is excluded during summer day. At night, Argentina coverage is excluded only west of about 70° W. Longitude due to modal interference.

Japan (H): The 10.2 kHz Japan signal is generally unavailable in the North Atlantic during the day except for the western part of the Gulf of

Mexico in the winter and in the extreme northeastern region of the North Atlantic. At night, the Japan signal covers regions west of about 75° W. Longitude and east of about 15° W. Longitude. In addition some long-path propagation may occur near the equator.

Composite Coverage

The use of the OMEGA Navigation System generally requires the availability of signals from three or more stations. The 10.2 kHz coverage assessment shows that the OMEGA system meets this requirement with the exception of a few small areas. During summer day, 10.2 kHz signals from only two OMEGA transmitting stations are accessible in 1) the western part of the Gulf of Mexico, 2) a small triangular area between Norway and the United Kingdom, and 3) a semi-circular area within the near-field zone of the Norway station. During both summer and winter day, 10.2 kHz signals from only two OMEGA transmitting stations are accessible within the near-field zone of the Liberian station. An analysis of 13.6 kHz signal coverage, however, indicates that use of this higher frequency would meet the coverage requirements in these areas with the exception of the extreme western part of the Gulf of Mexico during summer day.

In order to provide a fail-soft feature, i.e. a backup station if one station is off the air, it is necessary to have four station coverage. Several areas have been identified which do not have four station accessibility of 10.2 kHz signals. These are:

Summer Day:
a. Western Gulf of Mexico
b. 55° - 70° N. Latitude, 45° W. - 10° E Longitude
c. Near-Field zone of Liberia station

Summer Night:
a. Western Gulf of Mexico
b. 10° - 40° N. Latitude, 65° - 75° W. Longitude
c. Gulf of Guinea

Winter Day:
a. Mid - Gulf of Mexico
b. Near-field zone of Liberia

Winter Night:
a. Western Gulf of Mexico
b. 10° - 40° N. Latitude, 65° - 75° W. Longitude

The 13.6 kHz coverage analysis for summer day and winter night indicates significant improvement in four station fail-soft coverage when using this higher frequency. Areas not being provided with this fail-soft feature at 13.6 kHz are:

Summer Day:
a. Western Gulf of Mexico
b. Southeast Coast of Greenland
c. Small triangular area between Iceland and Norway

Winter Night:
a. Extreme western part of Gulf of Mexico
b. Southeast coast of Greenland

o ACCURACY ASSESSMENT

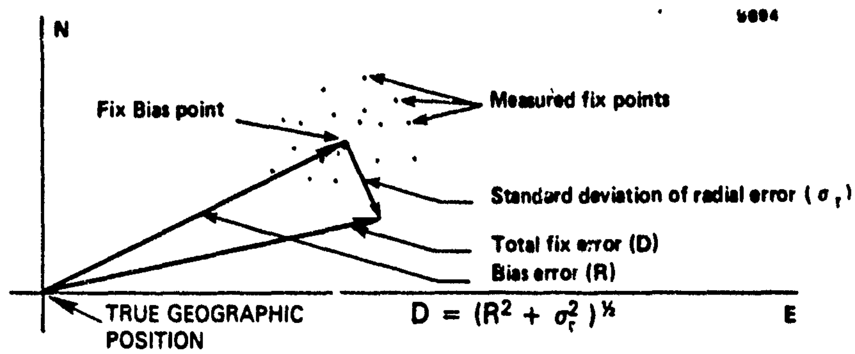
The characteristic accuracy of the OMEGA Navigation System as specified in the proposed Federal Radionavigation Plan [5] is:

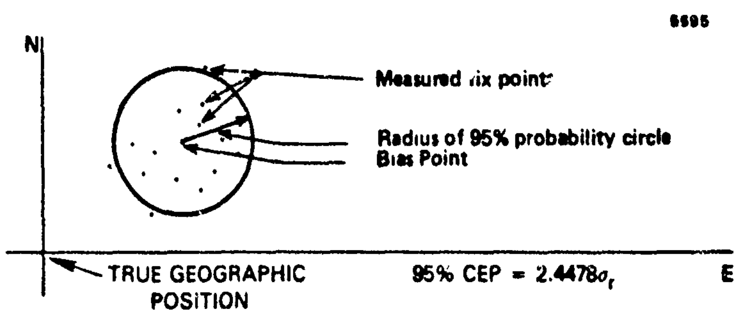
- Predictable Accuracy = 2-4 nm (2-drms)
- Repeatable Accuracy = 2-4 nm (2-drms)
- Relative Accuracy = 1-2 nm* (2-drms)

where 1) predictable accuracy is the accuracy of positioning with respect to geographical coordinates, 2) repeatable accuracy is the accuracy with which the user can return to a position whose coordinates have been measured previously with the same system and 3) relative accuracy is the accuracy with which a user can determine his position relative to another user of the same navigation system at the same time.

Definition of Terms

Three measures of fix errors have been considered as defined below;





*Experience has shown that a relative accuracy of 0.25 nm is achievable with OMEGA.[35]

where

a. R is the fix bias error which is the distance between the true position and the average measured position. The average measured position is known as the fix bias point. The fix bias error affects the predictable accuracy and is almost entirely due to propagation correction (PPC) error. Most of this error can be removed by PPC adjustments.

b. σ_r is the standard deviation of radial error about the fix bias point. This error measure indicates the stability of the fix, i.e. the random component of the error, and affects the repeatable accuracy of a fix.

c. D is the total error measure due to both the bias error (R) and random error (σ_r).

d. The radius of the 95% probability circle, centered at the fix bias point is equal to 2.4478 σ_r, assuming a circular bivariate Gaussian distribution.

Fix Accuracies

Figures 1, 2, 3 and 4 are maps showing recommended LOPs by geographical area for the lowest measured values of 1) the total error (D) and 2) the 95% CEP for summer day and winter night.

Average values of the total error (D) and the 95% (CEP) weighted by zonal area over the entire North Atlantic, based on the most accurate LOP combination in each zone, were calculated. These are:

Fix Error in Nautical Miles

	Total Error (D)	95% CEP
Summer Day	0.8	1.2
Winter Night	2.4	1.9

• CONCLUSIONS

Conclusions drawn from the analysis of the data collected for the validation of the OMEGA Navigation System in the North Atlantic region can best be expressed in terms of coverage and accuracy being provided by the system.

Coverage

The use of the OMEGA Navigation System generally requires the availability of signals from three or more stations. The 10.2 kHz coverage assessment shows that this requirement is met in the North Atlantic with the exception of a few small areas. However, except for the western part of the Gulf of Mexico during summer day, the

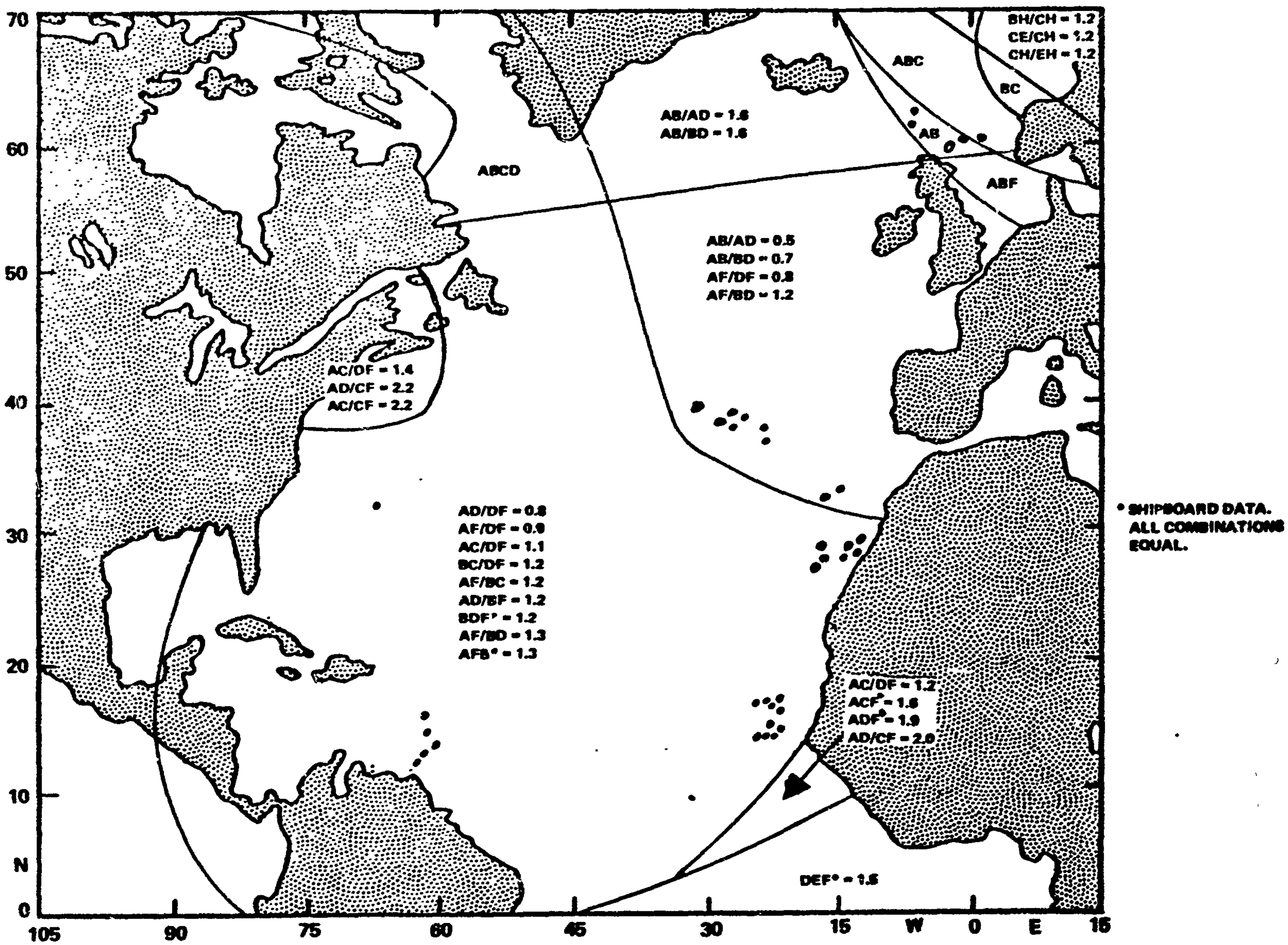


Figure 1 Recommended LOPs Based on Total Error (D), Summer Day 10.2 kHz

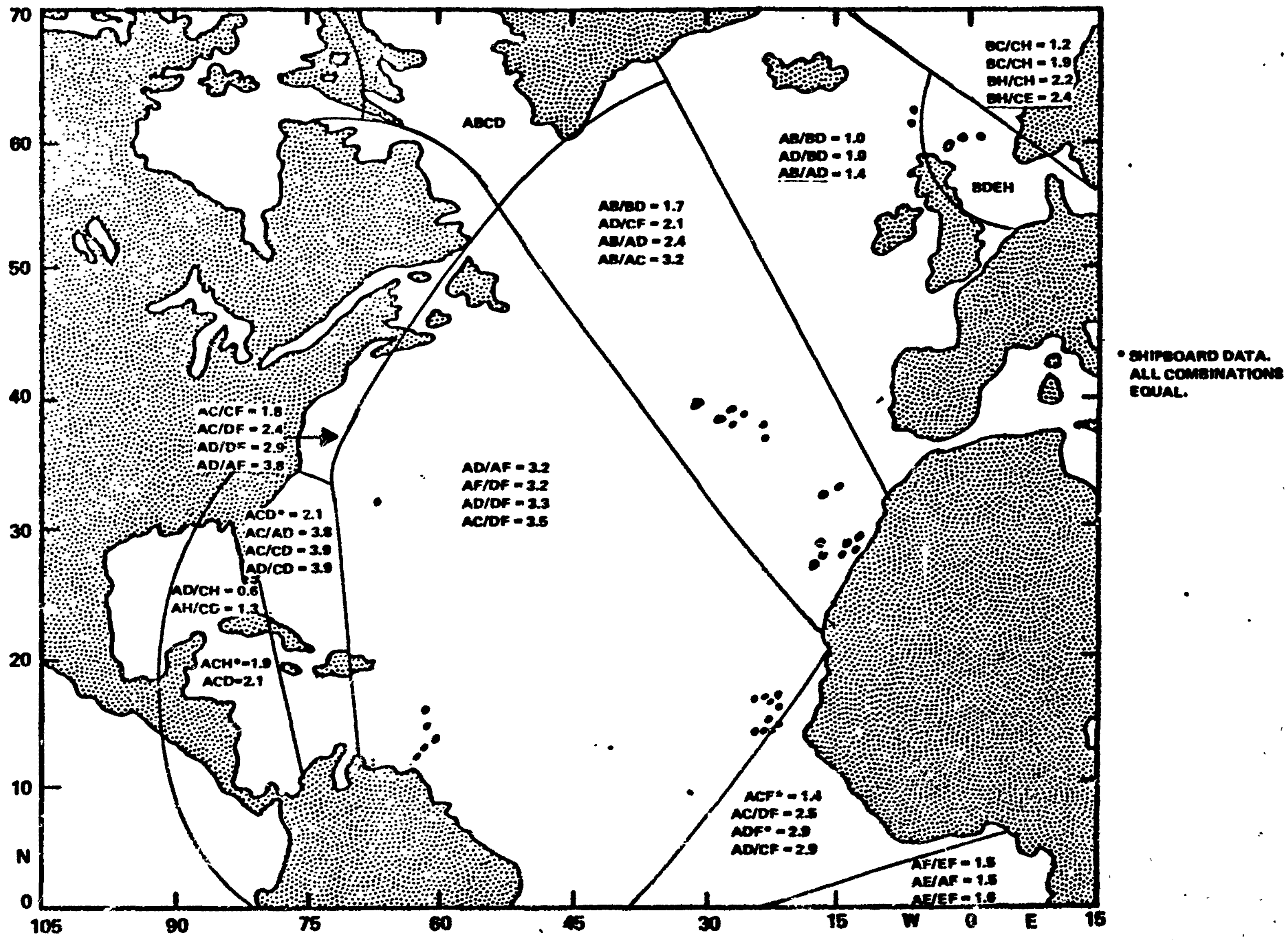
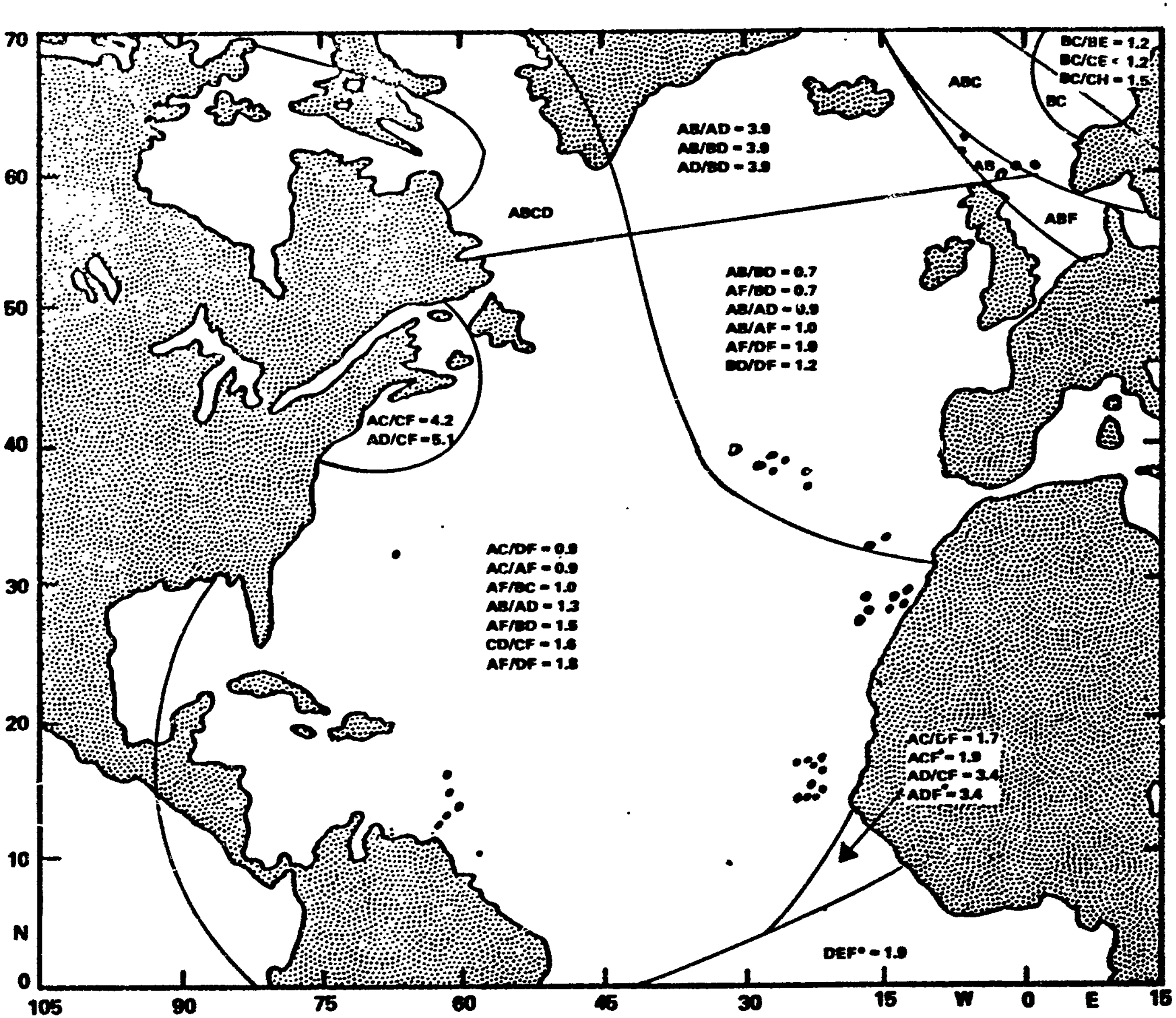


Figure 2 Recommended LOPs Based on Total Error (D). Winter Night, 10.2 kHz



* SHIPBOARD DATA. ALL COMBINATIONS EQUAL.

Figure 3 Recommended LOPs Based on 95% CEP, Summer D[illegible] 10.2 kHz

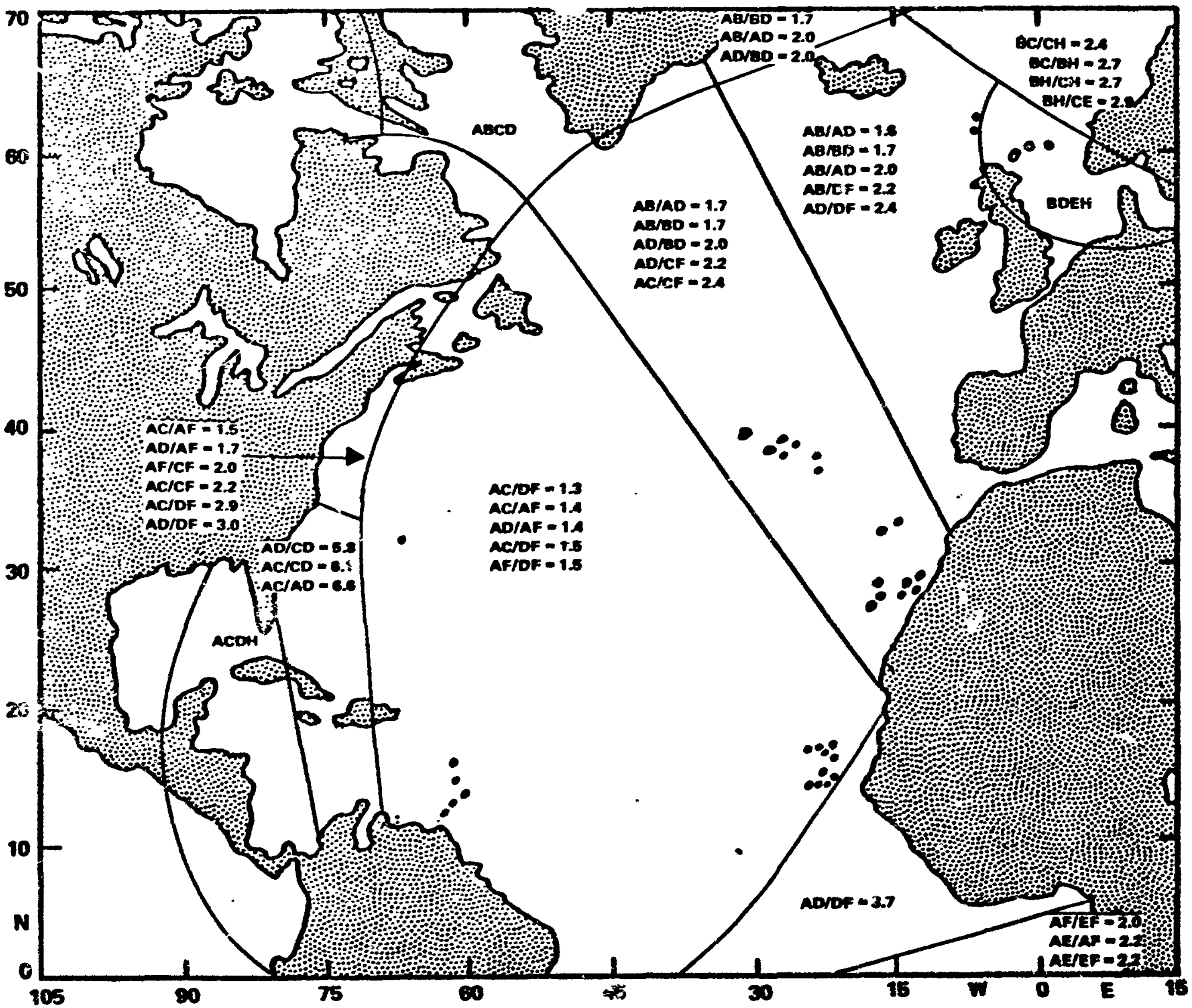


Figure 4 Recommended LOPs Based on 95% CEP, Winter Night, 10.2 kHz

OMEGA 13.6 kHz signals provide adequate coverage for those areas not covered at 10.2 kHz. Also, the use of the 13.6 kHz signals greatly reduces the geographical areas which do not have a four station coverage fail-soft feature at 10.2 kHz.

The coverage analysis also confirmed: 1) the lack of usable signals from the La Reunion (E) and Japan (H) Stations at all times in most of the North Atlantic, as predicted, and 2) the dependence on the Norway (A) signals, especially in the northeastern sector during summer day to achieve three station coverage. Predictions show that when the Australia (G) Station becomes operational, there will be a significant improvement in coverage in the southeastern Atlantic, the Caribbean Sea and the Gulf of Mexico during nighttime conditions.

Conclusions relating to other features affecting coverage are given below:

<u>Modal Interference</u> The NOSC airborne and ground station data confirmed the predicted 10.2 kHz nighttime modal interference zones in the North Atlantic for the Liberia (B) and Argentina (F) OMEGA stations. At 13.6 kHz, the data showed nighttime modal interference for Liberia very similar to the 10.2 kHz data except for flights between Liberia and Recife, Brazil where the 13.6 kHz signal was more severely disturbed. However, the Argentina signals at 13.6 kHz were less modally disturbed than the 10.2 kHz signals along the southeastern coast of the United States.

<u>Near Field Zones</u> The NOSC radial flights indicated that the extent of the near-field zone for Norway (A) is approximately 300 km (day) and 750 km (night) at 10.2 kHz and slightly larger at 13.6 kHz. Similar results were indicated for Liberia during the day, and the modal interference pattern at night encompasses the near-field zone.

<u>Long Path</u> The La Reunion (E) signals at both 10.2 kHz and 13.6 kHz recorded along the East Coast of the United States and in the Caribbean have been identified as long-path signals, i.e. signals propagating from along the longer of two great circle arcs between the transmitting station and the receiver. Such long-path signals cannot be used for navigating.

<u>Fix Accuracy at 10.2 kHz</u>

The characteristic accuracy of the OMEGA navigation system as specified in the proposed Federal Radionavigation Plan (5) is:

Predictable Accuracy = 2-4 nm (2-drms)

Repeatable Accuracy = 2-4 nm (2-drms)

Relative Accuracy = 1-2 nm (2-drms)

The civil marine requirement for safety at sea is a 2-4 nm predictable accuracy according to the Federal Radionavigation Plan (5).

The civil air requirement is that the standard deviation of the lateral track errors shall be less than 6.3 nm, i.e. 12.6 nm (2σ) (5, 34). This is specified in the Minimum Navigational Performance Specification (MNPS) developed under the auspices of the International Civil Aviation Organization (ICAO) (5, 34).

The analysis results show that by using the most accurate LOP combination, a total error (D) of 0.8 nm is achievable in the North Atlantic during summer day and 2.4 nm is achievable during winter night. Similarly, the 95% CEP achievable in the North Atlantic is 1.2 nm during summer day and 1.9 nm during winter night.

The 95% CEP figures are directly relatable to the required repeatable accuracy, expressed in terms of 2-drms, for the circular bivariate Gaussian distribution as follows:

$$\text{1-drms} = \sqrt{2}\ \sigma_r = 1.414\ \sigma_r$$

$$\text{2-drms} = 2.828\ \sigma_r$$

$$95\%\ \text{CEP} = 2.4478\ \sigma_r$$

$$\text{2-drms} = 1.155 \times 95\%\ \text{CEP}$$

Thus, the achievable repeatable accuracy for the OMEGA Navigation System in the North Atlantic is 1.4 nm (2-drms) for summer day and 2.2 nm (2-drms) for winter night. This is clearly within the civil air user repeatable accuracy requirements of the MNPS and the civil marine user predictable accuracy requirements of 2-4 nm for safety at sea.

The total error (D) is a combination of the bias error (R) and the standard deviation of the radial error (σ_r) and cannot be expressed in terms of 2-drms. It is, however, a measure of the predictable error and has been used in this study to better define the OMEGA system for the user. The bias error (R) is almost entirely due to PPC error and therefore most of this error can be removed by PPC adjustments.

A bias error analysis indicates that consistent phase difference biases are being measured at a number of the North Atlantic ground monitor sites.

• RECOMMENDATIONS

Three recommendations have resulted from this assessment of the coverage and accuracy being provided by the OMEGA Navigation System in the North Atlantic. These recommendations are:

- To investigate the efficacy of the -20dB SNR (100 Hz B.W.) criterion for signal coverage. New technology being implemented in receiver design offers an increase in receiver sensitivity for acquiring OMEGA signals, and an increase in noise reduction through new processing techniques. A relaxation in the criterion for signal coverage from -20 dB SNR to -30

dB SNR will result in a significant improvement in signal coverage for new technology receivers. Consistent with this advance in receiver technology, new signal coverage diagrams should be published which show SNR threshold contours at -30 dB.

- To remove bias errors through PPC improvements as soon as possible. The results included in this report indicate that the bias errors due to PPC corrections are normally greater than the random errors and form a major portion of the overall error. More specifically, elimination of the PPC errors of the type described in Table 6.5 of this report would result in at least a 30% improvement in overall accuracy (D). Improved propagation corrections should be developed in order that this imrovement can be realized.

- To recommend the use of multi-frequency receivers for improved coverage and accuracy. Analyses described in this report indicate that the use of 13.6 kHz signals improves signal coverage substantially. The OMEGA Navigation System offers additional frequencies which may be utilized to improve coverage and accuracy further. Signal coverage diagrams and propagation corrections should be developed for these additional frequencies.

1. INTRODUCTION

The OMEGA Navigation System provides a worldwide enroute positioning capability from eight transmitting stations. Although the operational transmitting stations now provide useful navigation signals, the system will not be declared fully operational until a coverage and accuracy verification program is completed. This coverage and accuracy verification is called validation and is being accomplished through a measurement program conducted by the U.S. Coast Guard on a regional basis. The program includes the collection of data from fixed monitor receiver sites to correct and update propagation models and tables, special calibration tests and the collection of operational data to confirm propagation parameters affecting coverage and availability [1,2,3]. As each geographic area is validated, the OMEGA system performance in that region will be defined and users will be advised of operational characteristics. The OMEGA system will be declared fully operational worldwide when the eighth permanent station becomes operational and signal accuracy and coverage in all regions have been validated. The validation process for the complete system will be accomplished by 1985.

The overall validation program is intended to substantiate OMEGA capability in several oceanic regions in the absence of other long-range navigation systems in those regions. The first region, a validation of OMEGA signals in the West Pacific Ocean was carried out in 1977 [4]. The validation of the OMEGA Navigation System in the North Atlantic is the second region in the U.S. Coast Guard's Regional Validation Program. The North Atlantic region of interest is an area bounded by longitudes 100°W and 15°E and latitudes 0°S and 70°N. A map is shown in Figure 1-1 to illustrate the region. In succeeding years, validation efforts will address the following ocean areas: North Pacific (1981), South Atlantic (1982), Indian Ocean (1983), and South Pacific (1984).

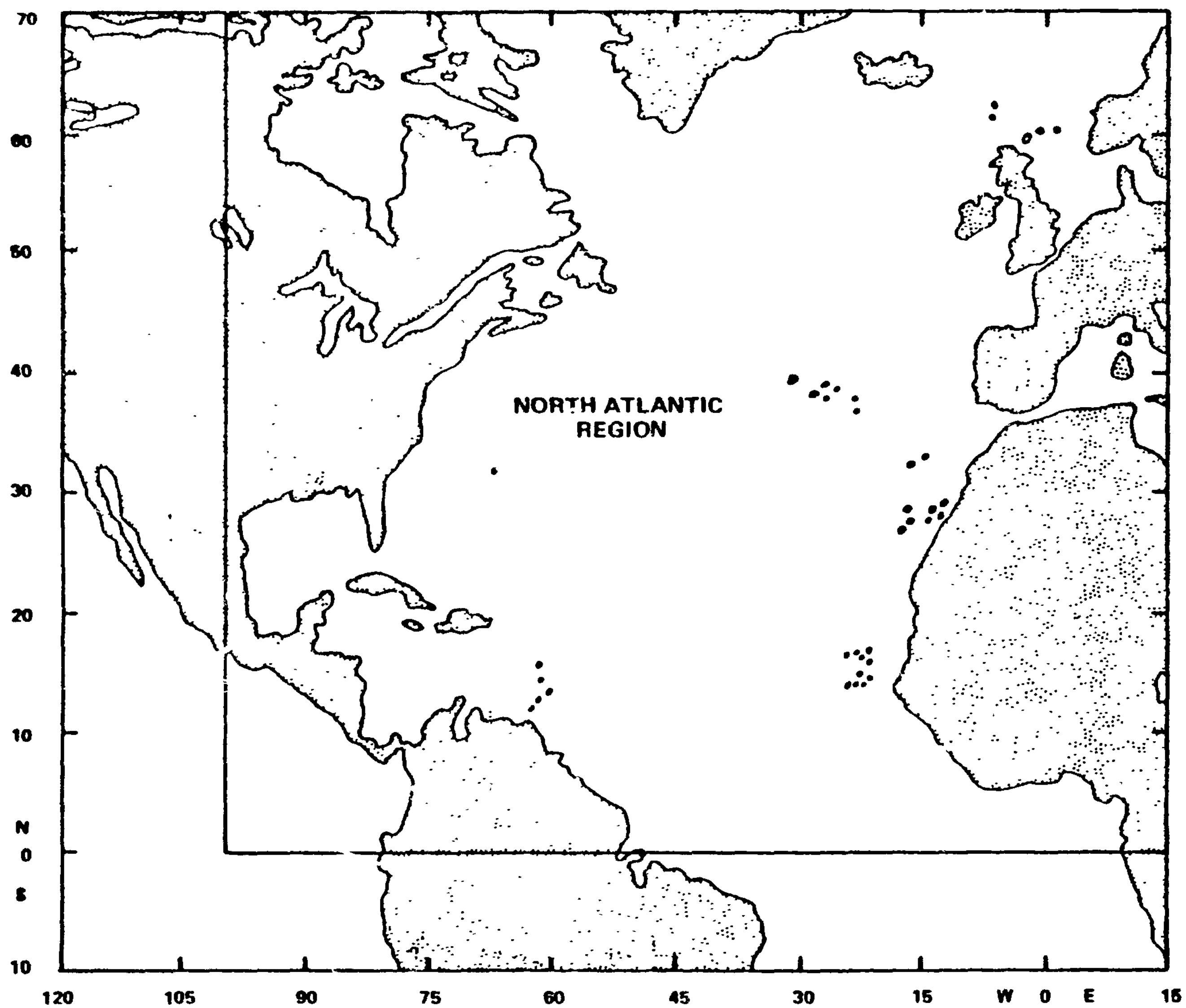


Figure 1-1 Map of ›rth Atlantic Region

2. BACKGROUND

The methodology and results of the OMEGA validation in the North Atlantic region are presented in later sections. A description of the OMEGA Navigation System and the factors which influence the accuracy of the system is provided in this section.

2.1 DESCRIPTION AND STATUS OF THE OMEGA NAVIGATION SYSTEM[5, 6]

The OMEGA Navigation System is a very low frequency (VLF), CW, phase comparison, circular or hyperbolic system. VLF propagation characteristics are such that eight (8) transmitting stations can provide worldwide signal coverage. At present, seven of the eight permanent stations are operating and the eighth, located in Australia, will be on the air in late 1980. Each station transmits four common navigational frequencies (10.2 kHz, 11.05 kHz, 11 1/3 kHz, 13.6 kHz) and a unique frequency. The transmissions from each station are time-sequenced to prevent interstation signal interference.

The characteristic predictable accuracy of the OMEGA Navigation System as specified in the proposed Federal Radionavigation Plan is 2 to 4 nm (2-drms)[5]. The accuracy actually achieved by a user depends on geographic location, station pairs used, accuracy of propagation corrections, receiver characteristics, and operator familiarity. The repeatable accuracy is 2 to 4 nm (2-drms)[5]. The relative accuracy is 1 to 2 nm (2-drms)[5], however, experience shows that a relative accuracy of 0.25 nm is attainable.[35] Definitions of these accuracies as defined in Bowditch[7] are as follows:

- Predictable accuracy is the accuracy of positioning with respect to geographical coordinates.
- Repeatable accuracy is the accuracy with which the user can return to a position whose coordinates have been measured previously with the same system.
- Relative accuracy is the accuracy with which a user can determine his position relative to another user

of the same navigation system at the same time. A system with a high relative accuracy provides good rendezvous capability for the users of the system.

Table 2-1 lists the OMEGA transmitting stations. A temporary station, located in Trinidad, is using the G station segment pattern which will be used by Australia when it becomes operational in 1980. All of the permanent stations (except Australia) are on the air, synchronized, and transmitting at a nominal radiated power of 10 kW at 10.2 kHz. The Trinidad station transmits at 1 kW.

Each of the OMEGA stations transmits in a prescribed time sequenced CW mode. This signal format (the OMEGA format) provides for transmission on 10.2 kHz, 11.05 kHz, 11.33 kHz. 13.6 kHz and a unique frequency, as illustrated in Figure 2-1. Each transmitter is identified by the pattern of segments which it transmits. A receiver uses the OMEGA format pattern to identify each of the stations it is monitoring.

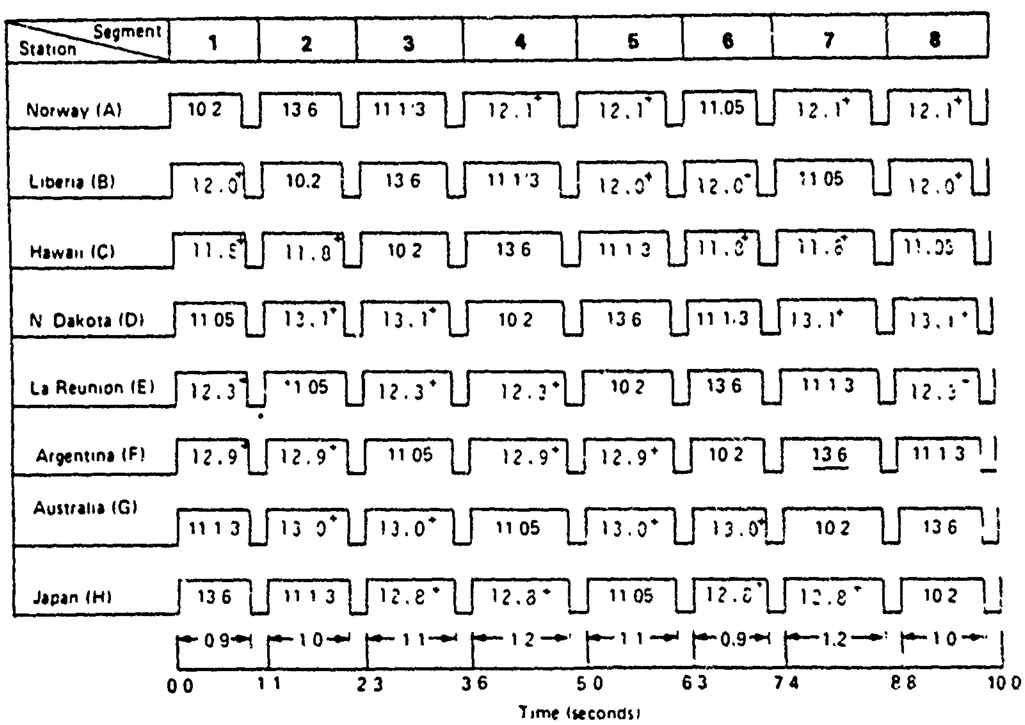


Figure 2-1 OMEGA Signal Transmission Format

TABLE 2-1
OMEGA TRANSMITTING STATION NETWORK

STATION LETTER DESIGNATION	SITE	LATITUDE/LONGITUDE	OPERATING AGENCY
A	ALDRA, NORWAY	66°25'N/13°08'E	Norwegian Telecommunications Administration
B	MONROVIA, LIBERIA	6°18'N/10°40'W	Liberian Ministry of Commerce, Industry and Transportation[1]
C	HAIKU, HAWAII	21°24'N/157°50'W	U.S. Coast Guard
D	LA MOURE, N.D.	46°22'N/98°20'W	U.S. Coast Guard
E	LA REUNION ISLAND, INDIAN OCEAN	20°58'S/55°17'E	French Navy
F	GOLFO NUEVO, ARGENTINA	43°03'S/65°11'W	Argentine Navy
G	WOODSIDE, AUSTRALIA[2]	38°29'S/146°56'E	Australian Dept. of Transportation
H	TSUSHIMA, JAPAN	34°37'N/129°27'E	Japanese Maritime Safety Agency

1. Station B, Liberia, is jointly operated by Liberian personnel and a U.S. Contractor.

2. A temporary station at Trinidad (10°42'N/61°38'W) under contract operation is transmitting in the G station segment pattern. The station in Australia is expected to become operational in 1980, at which time the Trinidad station will cease operation.

The OMEGA Navigation System is usable by ships, aircraft and land vehicles in either a hyperbolic or circular mode. In the hyperbolic mode, the standard OMEGA receiver measures the difference in phase between the signals transmitted from two time-synchronized stations. A minimum of two phase difference measurements are required to provide a fix. To obtain these two phase difference measurements, signals from three stations must be available at the receiver.

The circular mode of operation requires signals from only two stations to obtain a fix. However, the receiver, to operate in this mode, must have a precise time standard. Some of the latest receivers use the OMEGA signals to calibrate the receiver's oscillator thereby eliminating the requirement for an expensive internal time standard; the results are not as precise as using the hyperbolic mode of operation or from the use of precise oscillators and also require one to two hours of operation before useable position fixes are obtained.

Position fixing using OMEGA relies on the measurement of the relative phase between signals received from pairs of transmitting stations, or between a single station and a stable local oscillator if the circular mode is utilized. For a given pair of stations, the signals will have the same relative phase everywhere on a line which can be shown to be a hyperbolic Line Of Position (LOP). Furthermore, for the same two stations, the signals will have the same relative phase on many such LOPs. Without other information, it is impossible to determine which line of position a receiver is on for a single phase difference measurement. This situation is called lane ambiguity. Two lines of position representing equal phase differences form the boundary of an OMEGA lane. The receiver can determine the position within a lane but cannot distinguish among lanes.

The width of an OMEGA lane is dependent on the navigation frequency. Measured along the baseline between two stations, a lane for the 10.2 kHz frequency is approximately 8 miles (one-half wave-length) wide. The other frequencies produce characteristic lane widths, and it

is possible to use combinations of these to establish wider lanes. This technique is useful if an established lane identification is lost for some reason.

In the simplest form of operation, the OMEGA user will initialize his receiver when he is at a known location, thereby establishing lane identification. Then, while under way, lane counts are noted in a log as lane boundaries are crossed. Many modern receivers perform this function automatically.

Published OMEGA charts aid the navigator in establishing his position as well as resolving lane ambiguity. OMEGA charts show lines of position which are derived from theoretical radio wave propagation conditions. However, VLF radio wave propagation is affected by several spatial and temporal factors which must be considered in using OMEGA. Propagation Correction (PPC) tables are published which provide corrections to be applied to phase measurements made by a receiver. By adding the proper correction for the time and location as published in the PPC tables to the receiver phase measurements, the position may be plotted on OMEGA charts. A more sophisticated receiver can apply the PPC table corrections automatically and provide latitude and longitude coordinates of position.

Most of the OMEGA Navigation System error, at the present state of the art, is attributable to uncertainty in the factors related to VLF radio propagation. The VLF wave travels at nearly the speed of light but the velocity is affected by a number of conditions which will be discussed in the next section. It is necessary to understand the theory of VLF propagation in order to make a meaningful interpretation of the phase measurement. A variety of techniques including theoretical formulation, modeling and empirical observation, are used to study VLF propagation. The Hydrographic/Topographic Center publishes the PPC tables based on the Coast Guard model to make the results of this theory accessible to the OMEGA user. The PPC tables provide the user with corrections to be applied to phase measurements depending on the location of the receiver,

the time of day and the month of the year. These corrections compensate for temporal and spatial errors accumulated along the propagation path and are obtained from theoretical estimates modified by empirical measurements from the OMEGA monitor network.

2.2 OMEGA MONITOR NETWORK

The OMEGA Navigation System Operations Detail (ONSOD) maintains a worldwide monitor network. Each monitor consists of an OMEGA receiver and data logging equipment. The main purpose of these monitors is to provide data for use in preparing the PPC tables and to improve the modeling techniques used. The data are also being used for the OMEGA validation process. A list of the North Atlantic monitor sites is given in Table 2-2.

Data are available as far back as 1966 when the Norway and Hawaii transmitting stations were in operation. This data base has been augmented considerably with the addition of new monitor facilities and the commissioning of five additional transmitting stations, i.e., North Dakota (1972); Japan (1975); and Liberia, La Reunion, and Argentina (1976). Data have been collected using the Magnavox MX-1104 receiver at a number of monitor facilities since early in 1978. Prior to that time, data was collected using other types of receivers.

The data collected at these monitor sites are processed and stored on magnetic tape in the MASTERFILE data bank. The North Atlantic File contains 1870 blocks of 10.2 kHz data from 36 sites (Table 2-2) over the period 1966-1978. The data consist mainly of phase difference information. Each block contains one month of hourly phase differences at one frequency at a given monitor site for a given station pair.

TABLE 2-2

MONITOR NETWORK

NORTH ATLANTIC SITES ON 10.2 kHz MASTERFILE
Portsdown, U.K.
Bermuda, U.K.
Florida, USA
Trinidad, Site 2
NRL, Washington, D.C., USA
Hestmona, Norway
Keflavik, Iceland
Hammerfest, Norway
Cambridge, Massachusetts, USA
Farnborough, U.K.
St. Anthony, Newfoundland, Canada
Sardinia, Italy
Toulon, France
Miami, Florida, USA
Coral Harbor, Canada
Norfolk, COMOPTEVFOR
Oslo, Norway
Spitzbergen, Norway (identified as OSLO2 on the file)
Resolute, NWT, Canada
Montgomery, Alabama, USA
La Moure, North Dakota, USA
Piarco, Trinidad
Belem, Brazil
TASC, Reading, Massachusetts, USA
Nea Makri, Greece
Sabana Seca, Puerto Rico, USA
Vila Nova, Azores
Monrovia, Liberia
Yorktown, Virginia, USA
Canary Islands
Eglin Air Force Base, Florida, USA
Frobisher Bay, Canada
Lajes, Azores
Panama, Canal Zone
Portsmouth, Virginia, USA
Washington, D.C., USA

2.3 VLF PROPAGATION THEORY AND MODELS

VLF radio waves can be viewed as propagating in the waveguide bounded by the D-region of the ionosphere and the surface of the earth. Ideally, these signals would propagate with constant phase velocity and with generally low attenuation. This is true if the characteristics of the waveguide were homogeneous. However, there are several ways in which the waveguide formed by the ionosphere and the earth's surface differs from the idealized conception and each has a significant effect on VLF propagation.

2.3.1 Effects on VLF Propagation

The various effects of propagation path characteristics on VLF propagation are discussed in the following paragraphs.

Solar Ionospheric Effects

Signal propagation is affected by the daily variations in the ionization levels in the ionosphere. The diurnal variation in intensity of ionizing solar radiation produces changes in the nominal ionospheric reflection height from about 70 kilometers in the daytime to 90 kilometers at night. This in turn, affects the velocity of propagation of VLF radiowaves. Figure 2-2 shows typical variations in the recorded phase of a VLF signal over a one-day period.

The increase in phase delay at night results from the increase in the height of the ionosphere. This normal diurnal shift will be dependent on the sun's zenith angle and will vary on a daily, seasonal, and annual basis. The prediction of this diurnal effect is the dominant parameter in determining the phase of the VLF signal.

As can be expected, there will be greater attenuation of the signal in the daytime due to the decrease in the effective reflection height. However, since this greater daytime attenuation is not large, VLF signals can still travel over great distances.

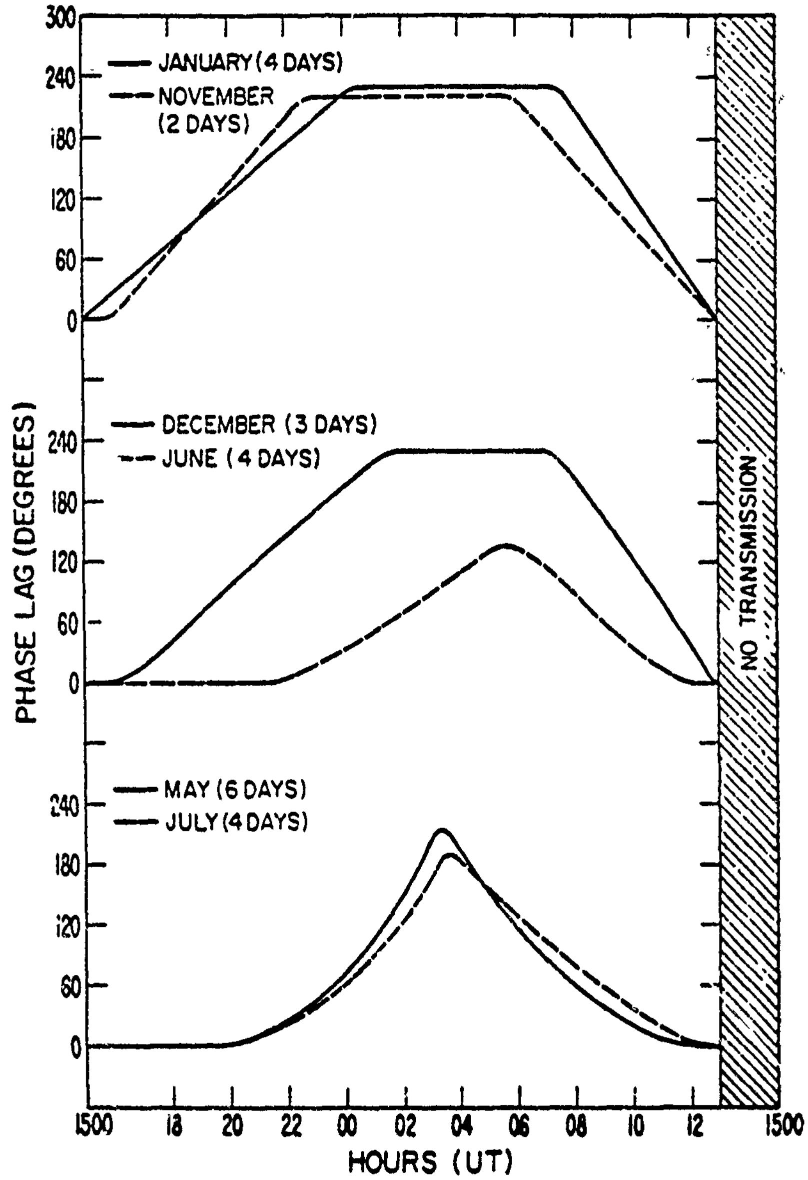


Figure 2-2 Diurnal Variation in the Phase of a VLF Signal Observed at Boulder, Colorado

Geomagnetic Field Effects

Asymmetry occurs in the attenuation rates of signals propagating in directions normal to the horizontal component of the earth's magnetic field. Figure 2-3 shows the strength of 10.2 kHz transmissions, propagating in a direction parallel to the direction of the earth's magnetic field, as a function of distance[8].

In the curve, the heavily shaded region shows field strength when propagating from north to south at distances noted on the abscissa. The lightly shaded region indicates transmission in the opposite direction, and for this direction, the distance scale on the abscissa must be reversed. As can be seen, the attenuation rate for north-south propagation is the same as for south-north propagation. Further study of this curve will indicate regions where the signal strengths of the same transmission traveling in opposite directions around the world start to approach each other in magnitude. This region is known as the antipode. It should be noted also that daytime attenuation is greater than nighttime. Without using sophisticated techniques to separate and detect these two signals, it is difficult to determine the phase of a one-way transmission traveling in a specific direction. Therefore, this places an upper bound on the useful range of transmission. The north-south curve indicates useful signals out to distances of 15,000 kilometers (9,200 statute miles).

Figure 2-4 [8] indicates the field strength of the 10.2 kHz signals propagating in directions normal to the earth's magnetic field, or from west to east (the heavily shaded region), and from east to west (the lightly shaded region).

These values are a function of latitude. This particular graph neglects changes in attenuation due to variations in ground conductivity. The daytime transmission toward the west in this example is attenuated at the rate of 4.4 dB/Mm, or more than twice the value of attenuation found in transmission toward the east. Transmission toward the west is only useful out to about 9,000 kilometers (5,600 statute miles), while transmission towards the east is sometimes useful out to about 18,000 kilometers, (11,000 statute miles).

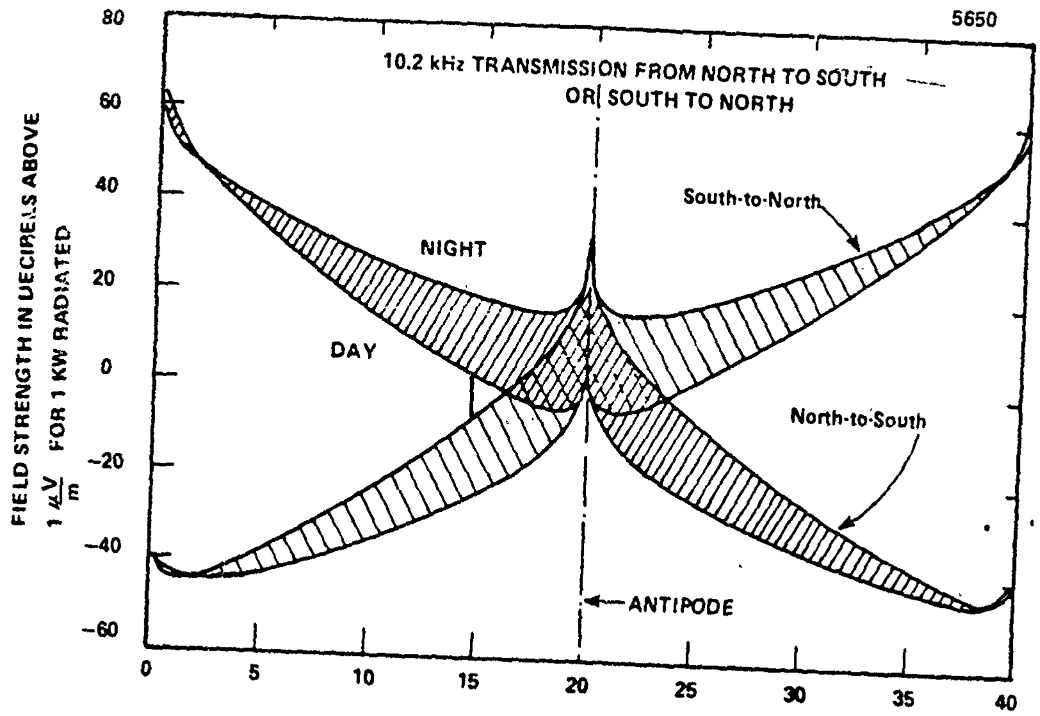


Figure 2-3 Transmission from North to South or South to North

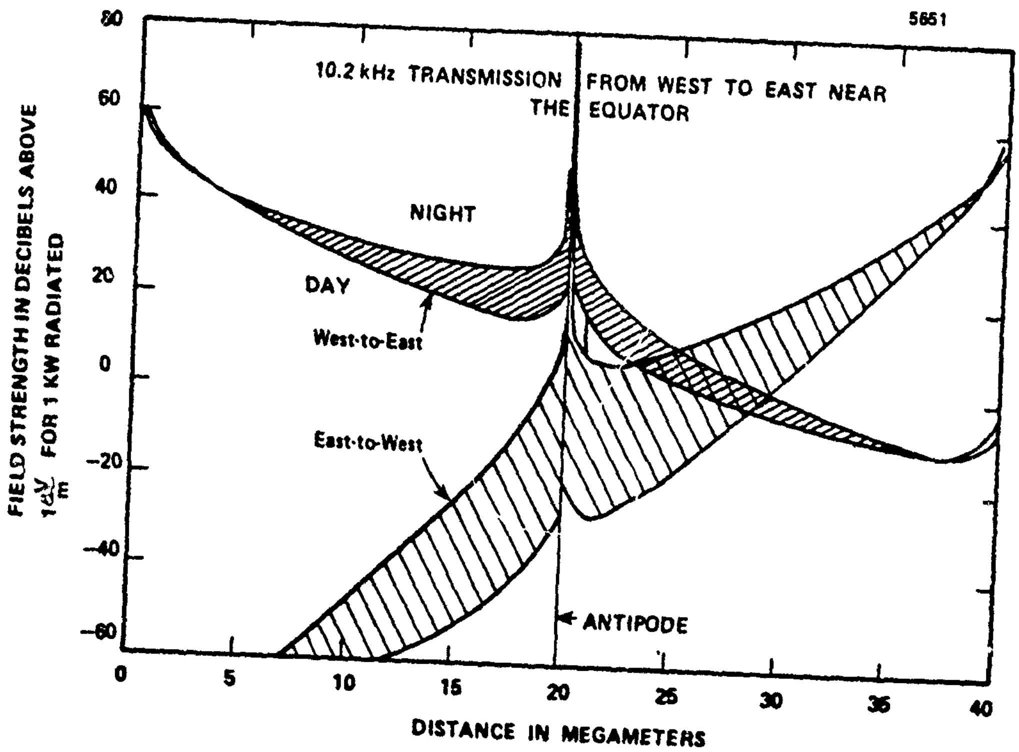


Figure 2-4 Transmission from West To East Near the Equator

Ground Conductivity Effects

In the non-ideal waveguide, we observe that the earth is not a perfectly conducting sphere, nor is its conductivity uniform. Figure 2-5 approximates typical conductivities within the North American continent. Conductivity values range from 4 mhos per meter over ocean areas to 10^{-5} mhos per meter in Arctic tundra regions. The effect of that change in conductivity is seen in Figure 2-6. The signal propagates over seawater with an effective attenuation rate of 3 dB per 1,000 km. The same signal, propagating over an ice path, is attenuated at a rate of 20 dB per 1,000 km.

ABNORMAL EFFECTS

These effects occur primarily from an active sun, sunspots, flares, and X-ray emissions. Most of these abnormal effects are not predictable. The ionospheric disturbances caused by the sun, which affect the ability to predict the phase velocity of the VLF signal, can be categorized into three distinct perturbation categories:

1. Sudden ionospheric disturbances (SID's)
2. Ionospheric storms
3. Polar cap absorption events (PCA's)

Sudden Ionospheric Disturbances

A sudden ionospheric disturbance (SID) is an increase in ionization of the ionosphere due to solar flare activity. It results in a lowering of the ionosphere and produces an apparent increase in the phase velocity (or an increase in phase of the signal).

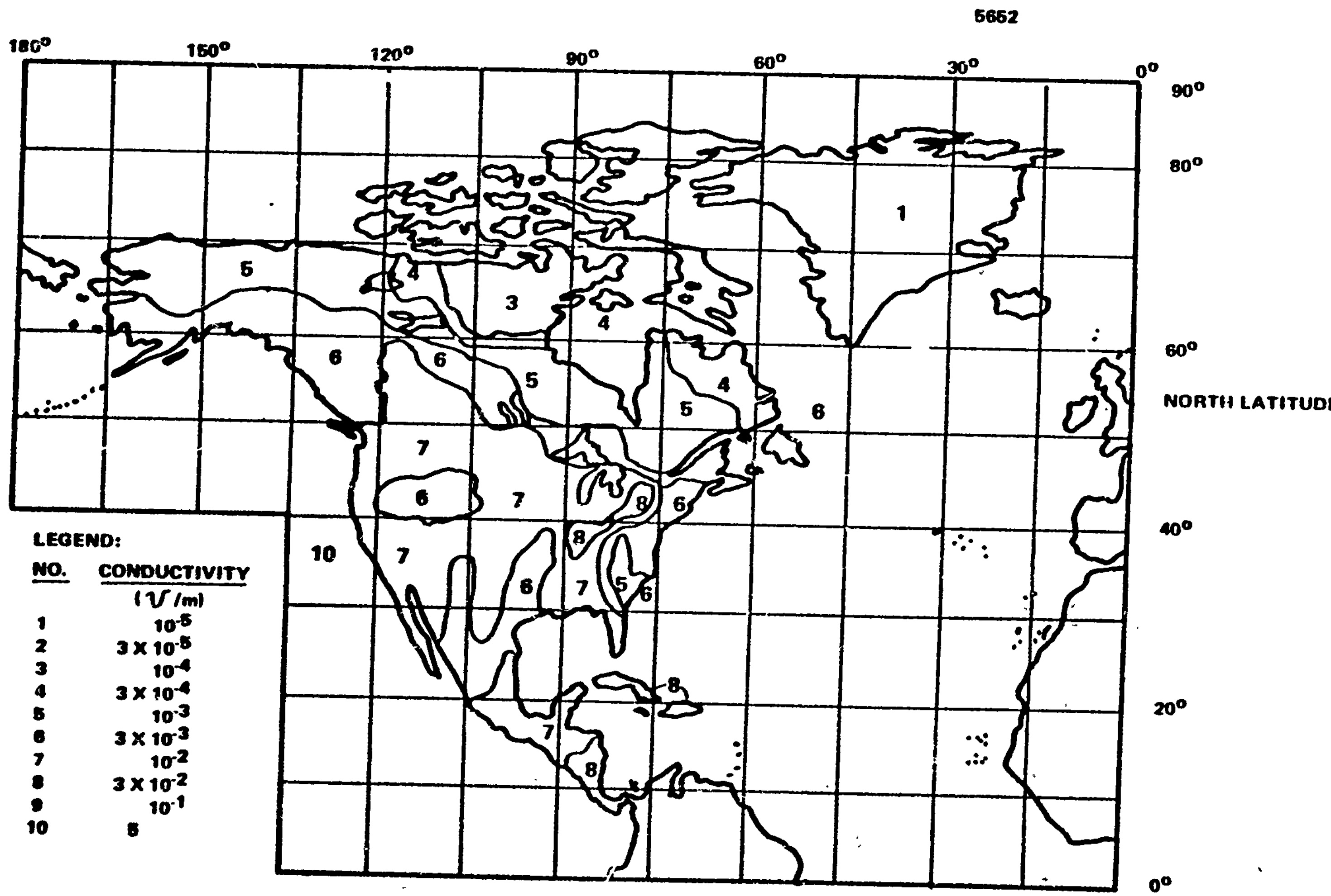


Figure 2-5 Conductivity Variation Within North American Continent

5663

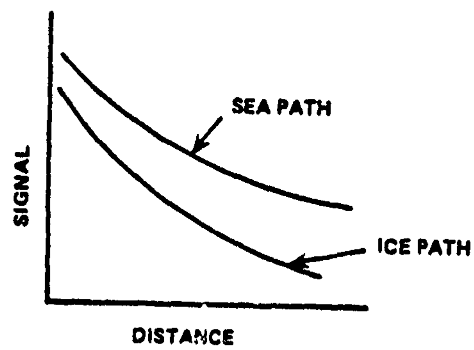


Figure 2-6 Conductivity Effects

The resulting changes in phase velocity due to solar activity cause the predictability of OMEGA signals to degenerate. Ionospheric lowering due to SID's caused by solar flare X-radiation can cause errors as high as 100 centicycles, or, equivalently, close to 10 nautical miles, for an all daylight path. These disturbances form in a matter of minutes after the flare begins and last 2 to 3 hours. Extreme flares ("M" type flares) have been recorded which caused errors for 12 hours, with a maximum phase shift of 20 centicycles. Although rare, they are of significance because of their duration.

An example of the effect of phase perturbations on propagation time during a large sudden ionospheric disturbance is illustrated in Figure 2-7. The SID associated with a solar flare began at about 1709 GMT on 8 July 1968.

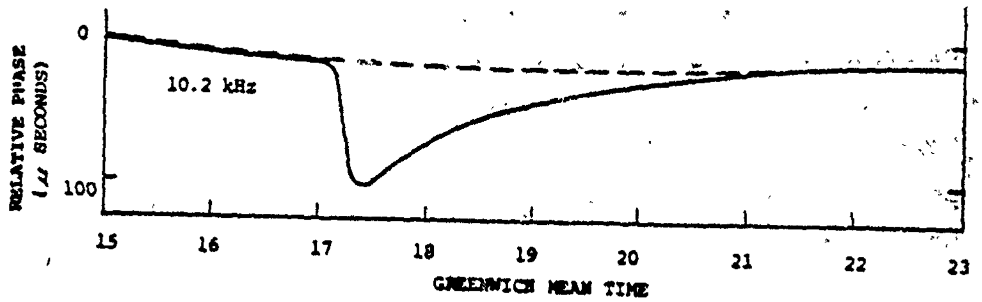


Figure 2-7 The Effects of a Large Sudden Ionospheric Disturbance

At 1725 GMT the propagation delay is about 100 μ seconds. This would introduce a position fix error of about 9.3 nm. The effect is long lasting — still present, although much reduced, 3 hours later.

Polar Cap Absorption (PCA)

PCA's cause extreme phase anomalies due to high-energy solar protons increasing the D-layer ionization and thereby reducing the reflection height down to altitudes on the order of 50 kilometers. These usually last on the order of one to three days. Within a few hours after solar flare occurrence, phase perturbations can be noted and usually absorption effects are evident.

The PCA event is located within the auroral zone, and occurs at high latitudes, as the name implies. Since the auroral zone extends to about 60° invariant latitude at night and about 78° during the day, the polar cap is defined to lie within a roughly oval shape interior to these latitudinal boundaries.

The proton flux is more intense at the polar cap and, by virtue of broken magnetic field lines in this region, more energetic particles are allowed to enter the ionosphere and penetrate to lower altitudes. This creates more intense ionization in the D-region and causes more pronounced phase shift and attenuation of a VLF signal here than elsewhere on the earth.

An example of this ıgation absorption is shown in Figure 2-8. Here transmissions i. ;orway as received at Cambridge, Massachusetts, are illustrated. This diagram shows the first two days of an average "Polar Cap Anomaly" (PCA) caused by corpuscular bombardment of the ionosphere by protons, and perhaps other charged particles, shot out in a solar eruption. The event shown began at approximately 10 GMT on 9 June 1968 and decreased in magnitude after about 40 hours.

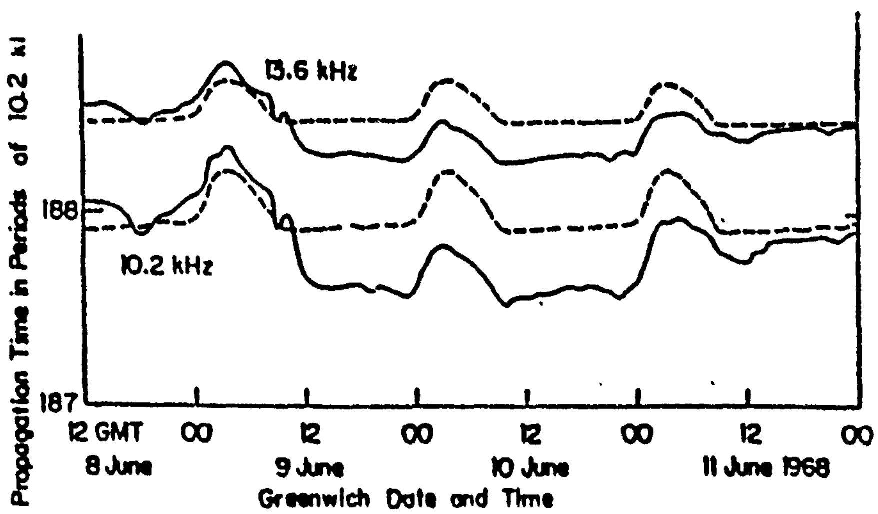


Figure 2-8 A Polar Cap Absorption Anomaly

Atmospheric Noise

At VLF, atmospheric noise rather than thermal noise is the limiting factor on signal reception and phase measurement. Lightning

discharges from electrical thunderstorms are the primary sources of atmospheric noise. This energy will propagate for large distances with little attenuation in the earth-ionosphere waveguide and therefore, seriously affect receiver operation. The peak of the RF energy spectrum, at great distances from the discharge, occurs at about 10 to 11 kHz. Since most lightning storms occur over the land masses near the equator and are almost non-existent at very high latitudes, atmospheric noise is most prevalent near the equator and then decreases with increasing latitude.

The main effect of noise is to introduce a phase error into the measurement. In general, however, degradation by atmospheric noise can be overcome by signal limiting in the receiver and by signal integration.

2.3.2 Theoretical Predictions

Theoretical calculations of OMEGA signal propagation have been performed to make a preliminary assessment of OMEGA signal availability in the North Atlantic as well as other areas. Modifying and extending a VLF propagation model formulated earlier by Budden, Dr. Pappert and his co-workers at the Naval Ocean Systems Center (NOSC) developed a numerical prediction scheme based on a waveguide-mode representation of VLF signal propagation.

After several years of refinement this computational model now furnishes reliable and accurate results, especially signal amplitude and phase behavior as a function of great circle distance from a signal source. Predictions from this model have been verified for a limited number of paths in the northern hemisphere, but the principal weakness lies not so much in the method itself but primarily in the uncertainty of the ionospheric parameters used in the model. Thus, although these prediction models are generally reliable, observational data is indispensable to the task of establishing the relationship between predicted and

actual signal behavior. Comparisons of predicted and measured signal behavior show very good correlation over portions of the signal paths and fairly sharp departures from modeled behavior in other regions. Significantly, these departures can be linked to distinct physical mechanisms, a factor of special importance in regional validation planning. One of the most fruitful aspects of the waveguide-mode prediction model, for the purposes of this effort, is that it shows where the OMEGA signal parameters achieve certain "threshold" conditions. These "signal threshold boundaries" indicate to a test designer where crucial observations of OMEGA signals should be made thus circumventing the need for exhaustive testing over all the area in a given region.

OMEGA monitor studies have shown that, under certain geophysical conditions such as time of day, propagation path azimuth, and geomagnetic field direction, signal phase does not exhibit the stability which must exist in order to accurately predict diurnal phase variation. Under these conditions departures from the expected phase variation can be significantly large and frequently unstable, making such OMEGA navigation signals unusable. In the conventional model of VLF wave propagation, this phenomenon is characterized as "modal interference".

The earth-ionosphere waveguide can support a number of signal components or "modes" having the same frequency, but slightly different phase velocities. Modal interference is a special form of signal interference wherein two or more waveguide modes interfere with each other and irregularities appear in the phase pattern. This type of interference occurs predominantly under nighttime conditions when most of the propagation path is non-illuminated and the boundary conditions of the waveguide are most irregular. It is most severe for signals originating at stations located close to the geomagnetic equator.

Based on known station locations and models for VLF signal behavior and noise phenomena, it is possible to generate predictions of likely OMEGA signal coverage based on the following criteria:

- Areas likely to be affected by near-field phenomena (i.e., areas close ($\sim$1Mm) to transmitting stations) are rejected.
- Areas likely to be affected by modal interference phenomena are rejected.
- Areas with S/N < -20 dB (based on atmospheric noise models in a 100 Hz bandwidth) are rejected.

These criteria establish the availability of OMEGA signals throughout a region. However, other factors affect the usability of the signals.

The accuracy obtainable for signals of equal amplitude and phase stability is affected by the geometric dilution of precision (GDOP). A useful theoretical tool is an error model and computational scheme developed for OMEGA hyperbolic and range-only position-fixing techniques. This model is used to compute the GDOP incurred in determining position coordinates. The signal path phase error model presumes error data from existing globally applied propagation corrections (PPC's). After the signal accessibility in a region has been determined using criteria defined in previous paragraphs, these models are applied to eliminate certain combinations of signals in areas that would lead to excessive positional error. In effect, pair selection of signals available in a certain region can be ranked by accuracy.

2.3.3 Models for Propagation Corrections [9]

Charts have been prepared for large areas of the world showing Line-Of-Position (LOP) lattices corresponding to several transmitting stations. These charts have been constructed on the assumption that VLF

radio waves travel with the same velocity in all directions. This means that any two observers having the same great-circle distance from a transmitter are assumed to record identical accumulated phases. Put another way, the basic postulate of LOP charting is that electromagnetic wave fronts emanating from a transmission source, i.e., the loci of points receiving equal phases, are circular on the surface of the earth. However, due to the non-uniform electromagnetic properties of the earth's surface and the ionosphere, together with diurnal variations and the presence of a geomagnetic field, the wave fronts are appreciably noncircular. Thus, the phase velocity of the wave depends significantly on the direction of propagation and consequently, a user's position, as determined by received phase and charts alone, will not coincide with his true position. Much experimental and theoretical investigation of VLF wave propagation has contributed to the calculation of these phase discrepancies. The results of these studies have been synthesized into a computer program which generates tables of phase corrections, termed propagation corrections (PPC's). Individual corrections are tabulated for $4^{\circ} \times 4^{\circ}$ regions of the world and a navigator simply algebraically adds the PPC difference computed for his region to the measured phase difference to obtain a more accurate LOP. These tables have undergone refinement and, currently, use of PPC's can yield positional accuracies of approximately one nautical mile. An example of a PPC table is given in Figure 2-9.

It should be mentioned at this point that a number of computational methods exist which could be used to calculate phase corrections. These programs stem from three alternative approaches to the phase prediction problem: (1) closed form, (2) full-wave, or (3) semi-empirical. These three modeling techniques are representative of the spectrum of techniques utilized to predict VLF signal parameters. The first two approaches listed above are primarily theoretical and not well-suited to modification by conventional experimental data. The semi-empirical approach consists of fitting "functional forms" to the dependence of phase variation (departure from nominal phase) upon certain independent parameters, e.g., ground conductivity along the path, path azimuth, and time

DATE																	LOCATION 16.0 N 40.0 W STATION A NORWAY
	GMT	00	01	02	03	04	05	06	07		18	19	20	21	22	23	24
1-15 JAN		-71	-71	-71	-71	-71	-71	-71	-71	.....	-24	-40	-61	-71	-71	-71	-71
16-31 JAN		-71	-71	-71	-71	-71	-71	-71	-68	.....	-20	-38	-57	-71	-71	-71	-71
1-14 FEB		-71	-71	-71	-71	-71	-71	-71	-59	.....	-18	-31	-52	-71	-71	-71	-71
15-28 FEB		-71	-71	-71	-71	-71	-71	-67	-44	.....	-09	-24	-46	-71	-71	-71	-71
1-15 MAR		-71	-71	-71	-71	-71	-70	-59	-32	.....	-06	-17	-39	-70	-71	-71	-71
....																	
6-31 DEC		-71	-71	-71	-71	-71	-71	-71	-71	.....	-28	-43	-66	-71	-71	-71	-71

Figure 2-9 Sample Propagation Prediction Correction Table

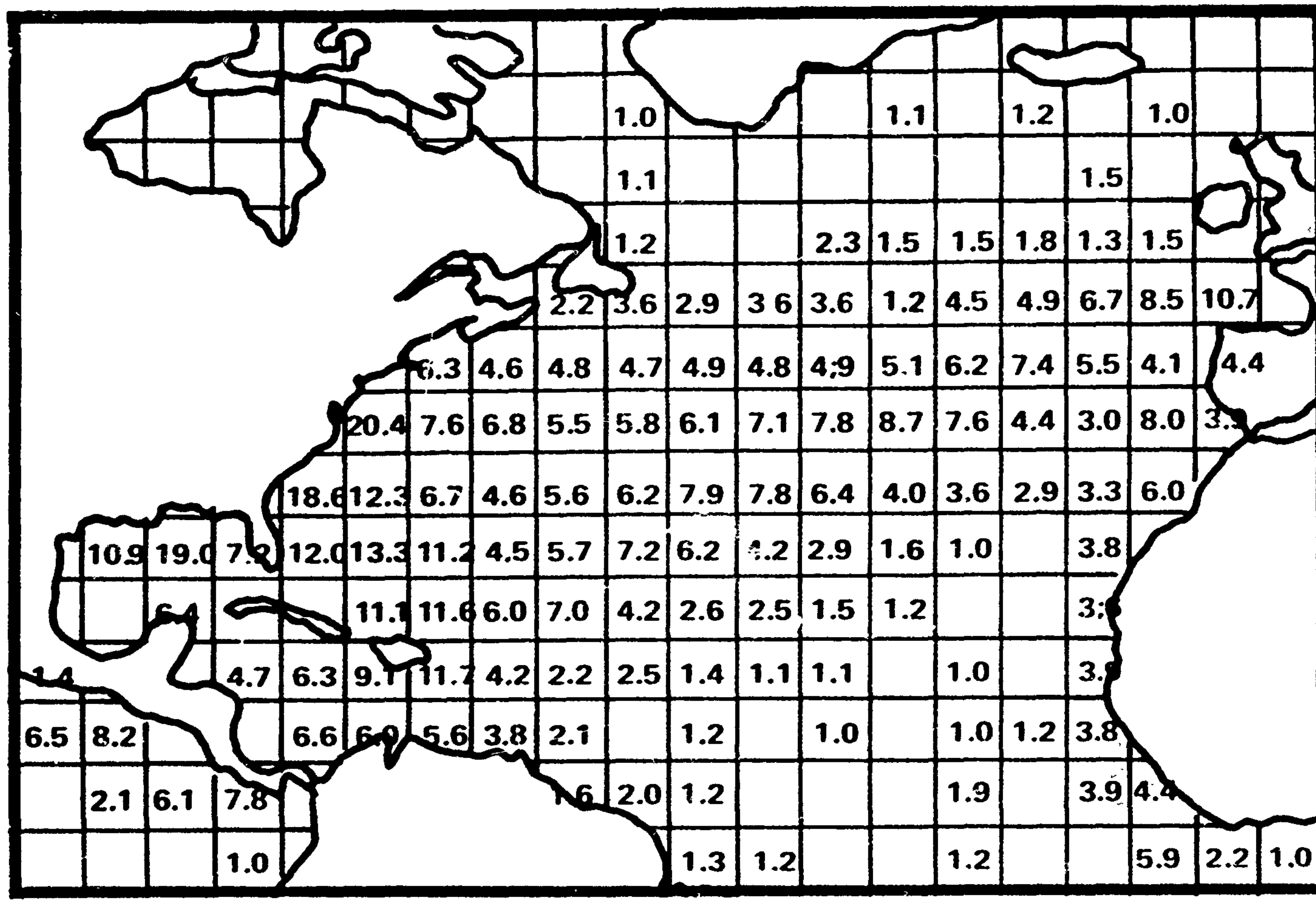
(month, day, hour). The sources of data from which the functional forms are derived include both observational results and information generated by computer programs based upon the full-wave method described above. One important advantage of the semi-empirical method is that its inherent statistical structure readily accommodates modifications necessary to conform to new data. Thus, only programs based on this semi-empirical technique currently provide propagation corrections of sufficient accuracy to be used on an operational basis.

2.4 OMEGA CAPABILITIES IN THE NORTH ATLANTIC

The North Atlantic is the area where the greatest number of users will rely on the OMEGA Navigation System for long range navigation. In addition to the general propagation features discussed above, other factors are prominent in this area:

- User Requirements - As Figure 2-10 clearly illustrates, ship densities in much of the North Atlantic Validation region are high. Statistics show that more than 50% of registered vessels are to be found in these waters. Both the wide dispersion of traffic routes and concentration of world shipping within the area stress the importance of defining user navigation requirements and of relating these requirements to the wide area service capability of OMEGA.

- Signal Accessibility - A more precise knowledge of signal/noise threshold contours is required to support user procedures for station selection/deselection. Signal degradation over Greenland and within the Greenland shadow is frequently reported and presents unique accessibility problems not present in other areas. Loss of Station H near the eastern edge of the shadow and sporadic performance of the Norway transmission within the shadow have been isolated as primary causes of lane loss problems. Poor reception of North Dakota near Northwest Europe has been frequently reported.



NOTE: SHIP DENSITIES LESS THAN 1.0 NOT PLOTTED

DATA SOURCE: AMVER STATISTICS, U.S.C.G.

Figure 2-10 Average Daily Merchant Ships in the North Atlantic Reporting to U.S. Stations, January 1972

- Accuracy - The ultimate goal of the validation effort is to verify the quality of navigation service provided and to better understand the temporal and spatial error distributions which define its accuracy. Reported accuracy performance in the North Atlantic ranges from "as predicted" to "poor" depending on the user, his experience and his receiver equipment. A Pan American/FAA flight test program(10) reported consistent accuracy in the 1 to 2 mile range due to the sophistication of the computer algorithms used. Other flight assessments have been reported by the Royal Air Force (11) and Laker Airways (12) with variable results. Seaborne users have reported 3 to 9 mile errors. The need for improved North Dakota PPC's to reduce a northwesterly error was cited and new coefficients were developed (13).

- Modal Interference - Given daylight conditions along the entire propagation path, the only region of modal interference is a more-or-less circular area of radius 500-1000 km immediately surrounding a transmitting station. If a given path is subject to modal interference under nightime conditions, then the path is likely to exhibit strong irregularities (e.g., cycle slips) when the path is under transition (change from night-to-day or day-to-night conditions).

  For the low-geomagnetic latitude transmitting stations (Liberia, Hawaii, Argentina, and Japan) the region of modal interference extends to the east approximately 2000 miles in a 20° - 30° sector. The northern hemispheric stations (Hawaii and Japan) show regions of modal inteference in the southwestern quadrant at all ranges. The Argentina station exhibits similar modal patterns except in the northwestern quadrant (relative to the station) rather than the southwestern quadrant. The Liberia station is nearly coincident with the geomagnetic equator and thus shows modal interference patterns in both the northwestern and southwestern quadrants in addition to a longer-range pattern to the east. The La Reunion and Australia (anticipated behavior) stations have higher geomagnetic latitudes and thus exhibit a pattern of modal interference in the northwestern quadrant beyond about 3000 miles in additon to a "near-field" region of approximately 1000 km radius. The high-latitude transmitting stations (North Dakota and Norway) are found to have no significant regions of modal interference outside the "near-field" (1000 km) region.

- Auroral Zone Signal Paths - The effective height of the ionosphere is reduced and the phase velocity is increased in the auroral zone. This zone is an annular ring which lies between latitudes 60° and 80° in both the Northern and Southern hemispheres. Propagation models consider the latitude and geomagnetic bearing angle for all midpath segments since both signal attenuation and phase velocity are dependent upon these factors. Above 60° North latitude, however, more uncertainty exists. In addition to different ionospheric characteristics, much of the North Atlantic/Auroral region of interest to this validation effort is characterized by extremely low ground conductivity. For values of ground conductivity decreasing below 0.14mho/m, theory predicts increasing phase velocity (with decreasing conductivity), whereas observation shows that phase velocity decreases with decreasing conductivity. Since Greenland exhibits the lowest conductivity of any earth surface area and also lies under the Auroral zone, this portion of the earth/ionospheric waveguide is not well defined by theoretical modeling. Figures 2-11 and 2-12 depict the Auroral zone and the relative phase velocity variation as a function of geomagnetic latitude within the zone.

- Long Path - Conditions occasionally prevail which are particularly favorable to very low frequency propagation paths and theory predicts this possibility in certain regions of the North Atlantic. Receiver tests conducted by Navidyne Corporation (14) showed that strong and stable La Reunion signals were regularly received throughout the Gulf of Mexico from the west. (15,000 miles rather than 10,000). Identification and isolation of a data base which will provide an estimate of where and when this condition may occur would benefit refinement of transmitter deselection procedures, especially for areas where long path transmission is com- mon.

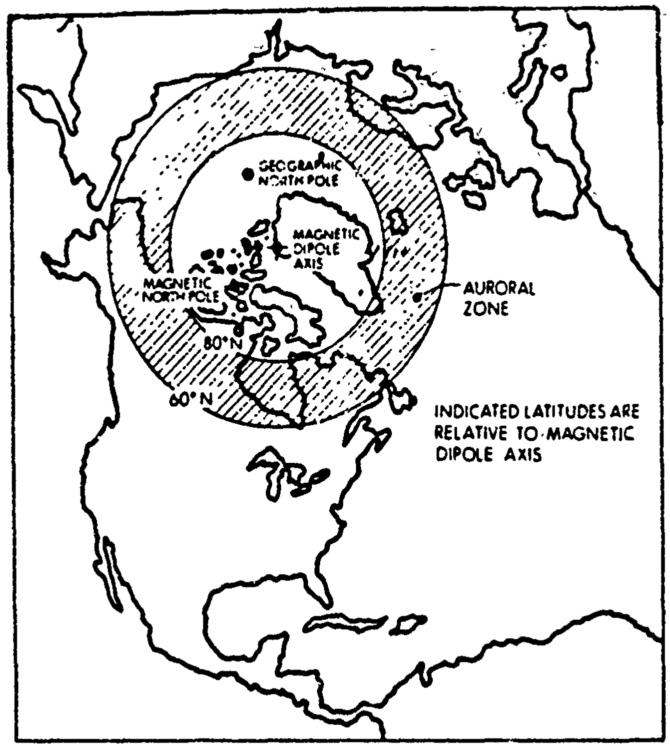


Figure 2-11   Effective Auroral Zone for VLF Propagation

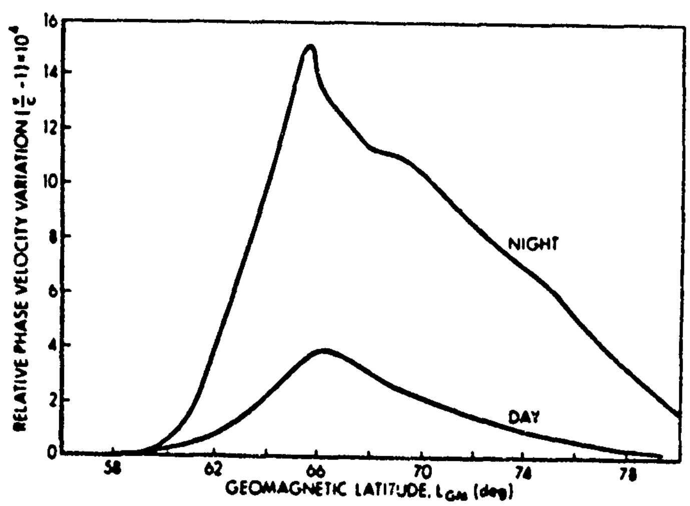


Figure 2-12   Relative Phase Velocity Variation in the Auroral Zone

3. VALIDATION METHODOLOGY

3.1 PREDICTED SIGNAL THRESHOLD BOUNDARIES

Coverage diagrams based upon predicted signal threshold boundaries for summer noon and winter midnight at 10.2 kHz are given in Figures 3-1 and 3-2 (2). These coverage diagrams show those areas where the signal-to-noise ratio (SNR) is greater than -20 dB (100 Hz bandwidth), and exclude areas likely to be affected by near field phenomena or modal interference. These coverage diagrams include Australia which will be part of the final OMEGA system and exclude the temporary transmitting station in Trinidad.

The predicted coverage diagrams were produced by developing a worldwide 10.2 kHz signal amplitude map for each of the eight transmitting stations and worldwide noise maps at 10.2 kHz. From these, SNR maps were produced upon which SNR threshold (-20 dB in a 100 Hz bandwidth) contours were drawn. These were then combined to produce composite coverage maps for two specific time-of-day conditions: (1) all-daylight, all-points at local summer noon and (2) all-night, all-points at local winter midnight.

3.2 PREDICTED FIX-ACCURACY DEGRADATION

In OMEGA, fix accuracy is not only dependent on measurement uncertainties and signal quality but also on geometric effects. The geometric effects are taken into account by a factor known as "Geometric Dilution of Precision (GDOP)". GDOP is dependent upon both the divergence of the hyperbolic lines of position and the LOP crossing angles. The relative divergence of hyperbolic lines derived from two stations is proportional to the cosecant of half the angle subtended by great circles from the observer's location to the two transmitting stations being measured. Thus the relative divergence with the observer along the baseline where the two stations subtend 180° will be unity (i.e., with no

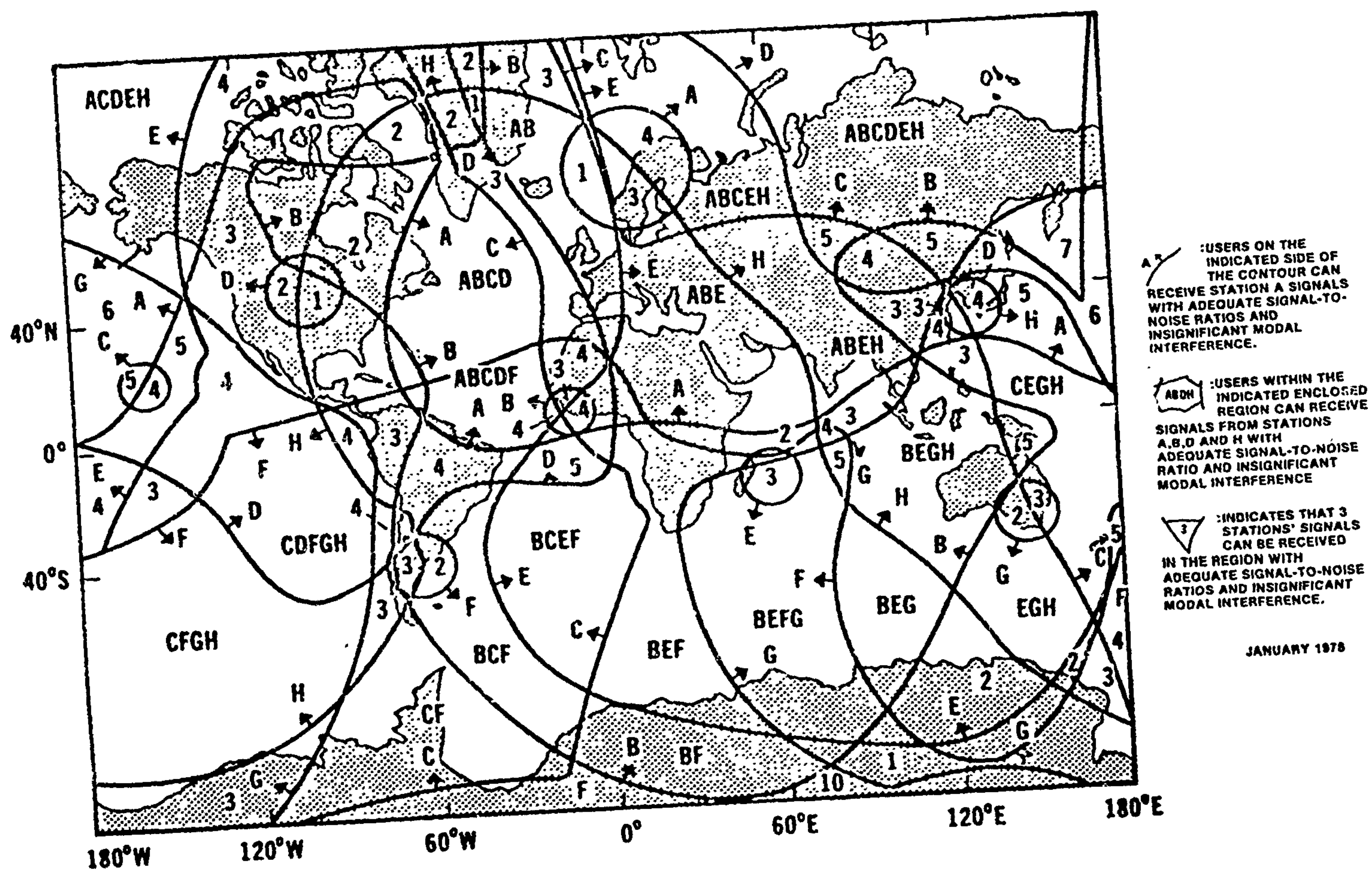


Figure 3-1 Composite Coverage Diagram, Full Sytem Local Summer (Approx. Mid-Summer) Noon

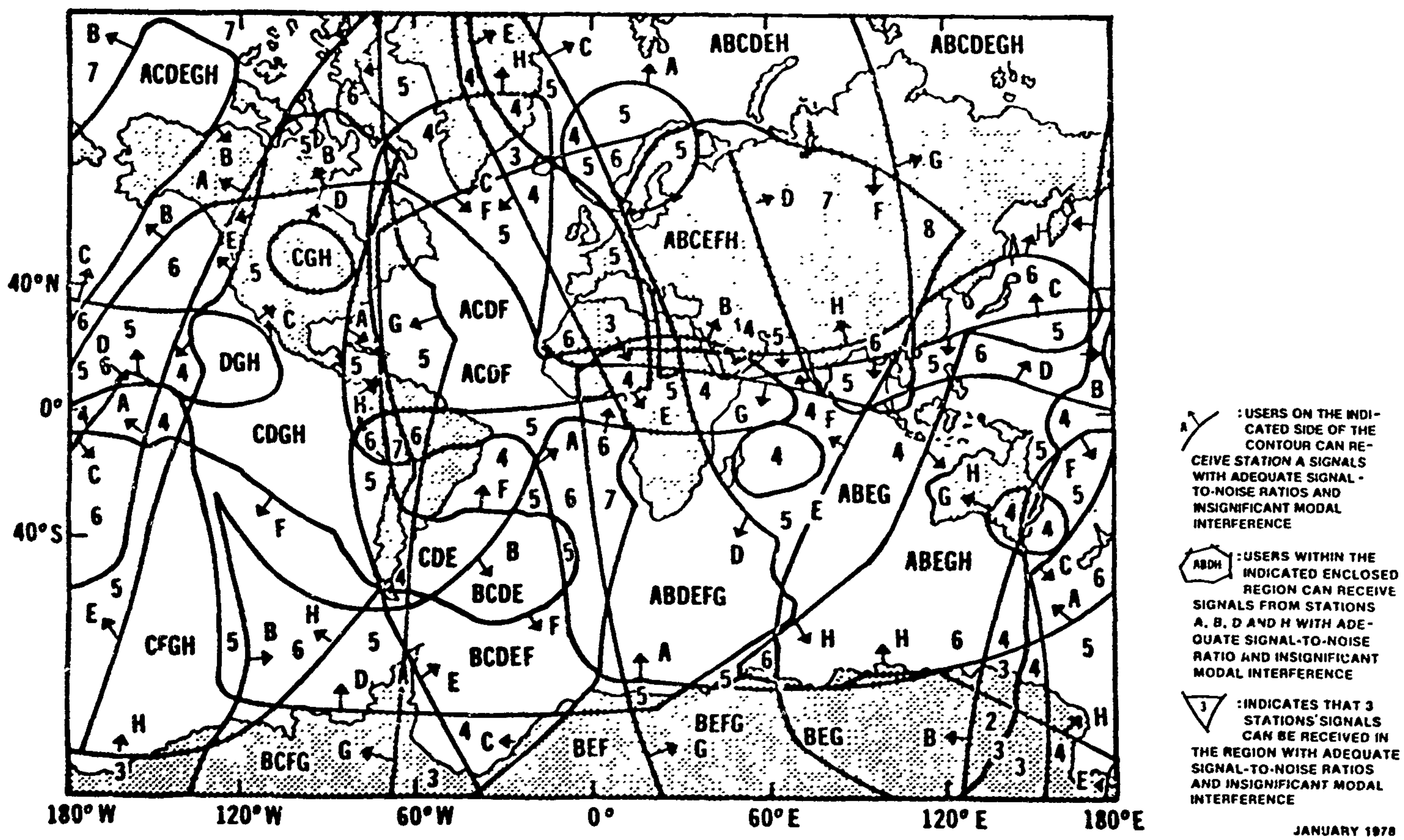


Figure 3-2 Composite Coverage Diagram, Full System Local Winter (Approx. Mid-Winter) Midnight

divergences, the spacing between sequential equi-phase hyperbola will be half the radio wavelength). At the other extreme, with the two stations located along the baseline extension (i.e., subtending 0°), the relative divergence is infinite.

At distances close to the baseline, LOP determination accuracy is affected very little since the LOP divergence is relatively small. As distance from the baseline becomes greater, there is an increase in LOP divergence which may produce a significant error in position. The effect of GDOP, then, is to magnify a given phase measurement error in terms of displacement in distance on the baseline to a distance many times greater at locations greatly separated from the baseline, but with the same phase measurement error.

The RMS fix accuracy degrades as the crossing angle of LOPs narrows. Position can be most accurately determined when two LOPs cross at an angle of approximately 90 degrees. An angle which varies significantly from this optimum may reflect a less precise location of position. To obtain an angle with a measurement close to 90 degrees, a navigator may select the most suitable LOPs from several LOP combinations.. This flexibility in developing a position determination is a feature unique to OMEGA.

3.3 EMPIRICAL DATA

A discussion of predicted signal threshold boundaries and fix accuracy degradation has been presented in Sections 3.1 and 3.2. The purpose of the OMEGA Navigation System Validation is to assess the coverage and accuracy being provided by the OMEGA Navigation System from measured data and compare it with predictions as a function of location and time. These measured data are comprised of signal amplitude data collected during tests conducted by the Naval Ocean Systems Center (NOSC) cooperatively with the Federal Aviation Administration Technical Center (FAATC), phase difference data collected at the ONSOD fixed monitor facilities and a variety of operational data. A more complete description of the data is given in Sections 4 and 7 of this report.

3.4 ANALYSIS AND INTERPRETATION

The first step in the analysis of the data was to assess the coverage being provided by the OMEGA Navigation System in the North Atlantic region at 10.2 kHz. The prime data for accomplishing this were the NOSC signal amplitude ground and airborne test data [15]. Using these signal amplitude data and International Radio Consultive Committee (CCIR)* noise predictions [16], SNRs were derived as a function of location, season and time for each of the OMEGA transmitting stations. From these data a contour for an SNR of -20 dB (allowing for modal interference and near field zones) was drawn on separate maps for each of the transmitting stations, for two seasons and two times of day (local day and local night). These contours were then overlaid to produce composite coverage maps based on measured data. These were then compared with the predicted 10.2 kHz composite coverage maps.

Based on the coverage assessment, the next step in the analysis was to evaluate the quality of the accessible signals. The prime data for accomplishing this were the ONSOD ground station 10.2 kHz phase difference data. First, enough data to provide a meaningful sample were processed for each available LOP at as many ground stations as possible. After processing, these data were manually screened to determine which months and which LOP pairs were suitable for further processing to determine position-fix accuracies. The determining factors included the size of the standard deviation of the phase error (i.e., random error) and the bias error being observed. Large bias errors were further examined to determine if they were being caused by modal interference or were truly a bias in the measurements. If the latter was true, the data were retained for further analysis.

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*Although airborne noise measurements made by NOSC were very sparse, a comparison of these values with those of CCIR indicated fairly good agreement. CCIR noise levels have therefore been used throughout this analysis.

The third step in the validation was to determine the position fix accuracies that are being provided by OMEGA in the North Atlantic region at 10.2 kHz. The prime data for this analysis were the selected ONSOD processed ground station data supplemented with the integrated OMEGA/Satellite shipboard data. The position-fix accuracies were computed as a function of geographic location, LOP pair, season and time of day.

Additional analysis tasks included a signal coverage assessment at 13.6 kHz for comparison with the 10.2 kHz coverage, a phase difference bias error study, and investigation of the effects of SIDs on OMEGA fixing accuracy.

3.5 COMPARISONS AND CONCLUSIONS

The measured coverage and accuracy being provided by OMEGA in the North Atlantic region have been compared with predictions of coverage and accuracy. Conclusions drawn concern signal accessibility, achievable fix accuracy and effectiveness of the PPC model. Also, an assessment has been made as to how well the OMEGA Navigation System meets the maritime and air user requirements in the North Atlantic region.

4. DESCRIPTION OF DATA

Data used in this validation report is classified in two major categories: non-test data and test data. These classifications reflect differences in processing requirements for the long term, relatively permanent fixed monitor sites as distinguished from the short term data collection effort by NOSC which focussed on the North Atlantic validation only.

4.1 NON-TEST DATA

The non-test data consist of fixed OMEGA monitor data and integrated OMEGA/Satellite shipboard data collected by ONSOD to measure system performance.

4.1.1 Fixed OMEGA Monitor Data

The 10.2 kHz North Atlantic MASTERFILE used in this report consists of 1870 blocks of data from the period 1966-1978. Each block contains one month of hourly phase differences at a given frequency at a monitor site for one station pair. A list of these stations is provided in Table 4-1 and a map showing their locations is given in Figure 4-1.

A listing of all the data for each monitor site is given in tabular form in Appendices A and B as a function of transmitting station or LOP station pair and time (month/year). The data have been divided into two parts: 1) transmitter monitor stations and 2) all other monitor stations. The transmitter monitor station data have been separated from the other data as it is close to being single station phase data. However, it is recognized that this is not true in the strictest sense as the monitor stations are not co-located with the transmitting stations.

-ll cases, data from the early Forestport, N.Y. (designated I) and from the Trinidad Station (temporarily in the G station segment) have

TABLE 4-1

MONITOR NETWORK

NORTH ATLANTIC SITES ON 10.2 kHz MASTERFILE
Portsdown, U.K.
Bermuda, U.K.
Florida, USA
Trinidad, Site 2
Washington, D.C., USA (NRL)
Hestmona, Norway
Keflavik, Iceland
Hammerfest, Norway
Cambridge, Massachusetts, USA
Farnborough, U.K.
St. Anthony, Newfoundland, Canada
Sardinia, Italy
Toulon, France
Miami, Florida, USA
Coral Harbor, Canada
Norfolk, Virginia, USA (COMOPTEVFOR)
Oslo, Norway
Spitzbergen, Norway (identified as Oslo2 on the file)
Resolute, NWT, Canada
Montgomery, Alabama, USA
La Moure, North Dakota, USA
Piarco, Trinidad
Belem, Brazil
Reading, Massachusetts, USA (TASC)
New Makri, Greece
Sabana Seca, Puerto Rico, USA
Vila Nova, Azores
Monrovia, Liberia
Yorktown, Virginia, USA
Canary Islands
Eglin Air Force Base, Florida, USA
Frobisher Bay, Canada
Lajes, Azores
Panama, Canal Zone
Portsmouth, Virginia, USA
Washington, D.C., USA

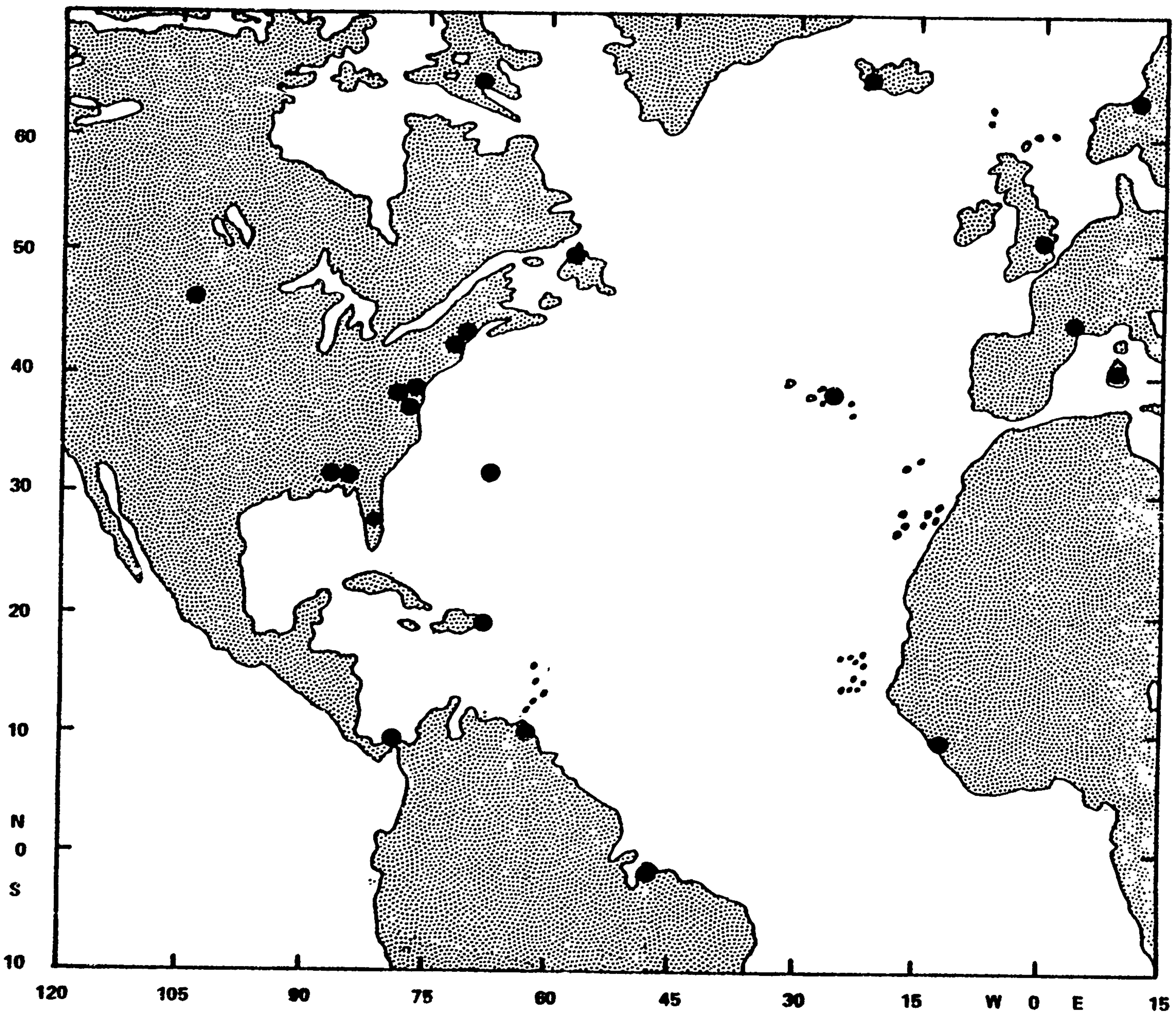


Figure 4-1. Location of OMSOD Monitor Facilities

been deleted in the tables as neither station is intended to be part of the permanent OMEGA network.

In addition, the time of day is indicated and flags are noted. The definitions for the flags are as follows:

S - Data block failed phase error variance test

Q - Insufficient data in block for phase error variance test

B - Large phase error bias for data block

E - Large rms phase error for data block

F - All data in block are flagged

These flags are associated with monthly, station pair data blocks. The presence of an F-flag disqualifies the entire data block but the other flags indicate that only some of the data in the block is invalid and the block is retained for processing.

A summary of the total phase data available from each transmitter monitor site is given in Table 4-2 and phase difference data for all other monitor sites in Table 4-3.

4.1.2 Integrated OMEGA/Satellite Shipboard Data

The Integrated OMEGA/Satellite data consists of measurements made aboard the following ships during 1978 on cruises indicated on a map, Figure 4-2. The equipment used was a Magnavox MX 1104 modified to receive and process Navy Navigation System Satellite (NNSS) data simultaneously with the OMEGA signals. Since this receiver combines elements of the MX 1102 satellite receiver with the MX 1104 OMEGA receiver, it has been designated MX 1102/04

Vessel	No. Satellite Fixes
ANCHORAGE	350
WESTWIND	200
GALLOWAY	150
AFRICAN NEPTUNE	300

TABLE 4-2

SUMMARY OF ONSOD 10.2 KHZ
MASTERFILE TRANSMITTER MONITOR STATION DATA*

SITE	YEAR	TOTAL LOP/MO.
HESTMONA, NORWAY	1967	7
	1968	12
	1969	12
	1970	11
	1971	12
	1972	14
	1973	11
	1974	13
	1975	26
	1976	27
	1977	31
	1978	8
LA MOURE, N.D.	1973	7
	1974	14
	1975	27
	1976	17
	1977	21
	1978	6
MONROVIA, LIBERIA	1976	11
	1977	8
	1978	6
PIARCO, TRINIDAD	1971	2
	1972	23
	1973	21
	1974	20
	1975	24
	1976	14
	1977	14
	1978	4
TRINIDAD, SITE 2	1967	18
	1968	22
	1969	24
	1970	24
	1971	20
	1972	10
	TOTAL	541

*STATION (G) TRINIDAD AND (I) FORESTPORT NOT INCLUDED IN BLOCK COUNT

TABLE 4-3

SUMMARY OF ONSOD 10.2 KHZ
MASTERFILE GROUND STATION PHASE DIFFERENCE DATA*

SITE	YEAR	TOTAL LOP/MO.
BELEM, BRAZIL	1974	8
	1975	34
	1976	24
BERMUDA	1966	1
	1968	2
	1969	12
	1970	11
	1971	12
	1972	14
	1973	9
	1974	14
	1975	13
	1977	6
	1978	36
	1979	12
CAMBRIDGE, MA.	1968	2
	1969	8
	1978	5
	1979	15
CORAL HARBOR, CAN.	1971	5
	1972	5
EGLIN AFB, FLA.	1977	6
	1978	30
	1979	24
FARNBOROUGH, U.K.	1972	1
	1973	4
	1974	12
	1975	9
	1976	15
FROBISHER, CAN.	1977	6
HAMMERFEST, NOR.	1968	12
	1969	7
KEFLAVIK, ICELAND	1977	6
	1978	18
LAJES, AZORES	1978	12
	1979	18
MIAMI, FLA.	1971	1
NEA MAKRI, GREECE	1975	12
	1976	19
	1977	12

*STATION (G) TRINIDAD AND (I) FORESTPORT NOT INCLUDED IN BLOCK COUNT

TABLE 4-3 (CONT'D)

SUMMARY OF ONSOD 10.2 KHZ
MASTERFILE GROUND STATION DIFFERENCE DATA*

SITE	YEAR	TOTAL LOP/MO.
NELC, CA.	1972	1
	1976	4
NORFOLK, VA.	1971	1
	1972	5
	1973	2
	1974	9
	1975	
NRL, WASH. D.C.	1967	2
	1968	9
	1969	12
	1970	2
OSLO (2), NORWAY	1971	7
PANAMA, C.Z.	1978	54
PORTSMOUTH, VA.	1978	54
	1979	18
RESOLUTE BAY, CAN.	1971	5
	1972	2
SABANA SECA, P.R.	1975	21
	1976	29
	1977	35
	1978	12
SARDINIA, ITALY	1973	4
	1974	10
	1975	8
	1978	13
ST. ANTHONY, NFLD.	1968	1
	1969	11
	1970	2
	1977	6
TASC, READING, MA.	1974	5
	1975	7
VILA NOVA, AZORES	1975	5
	1976	28
	1977	8
WASHINGTON, D.C.	1978	42
	1979	18
YORKTOWN, VA.	1976	3
	TOTALS	928

*STATION (G) TRINIDAD AND (I) FORESTPORT NOT INCLUDED IN BLOCK COUNT

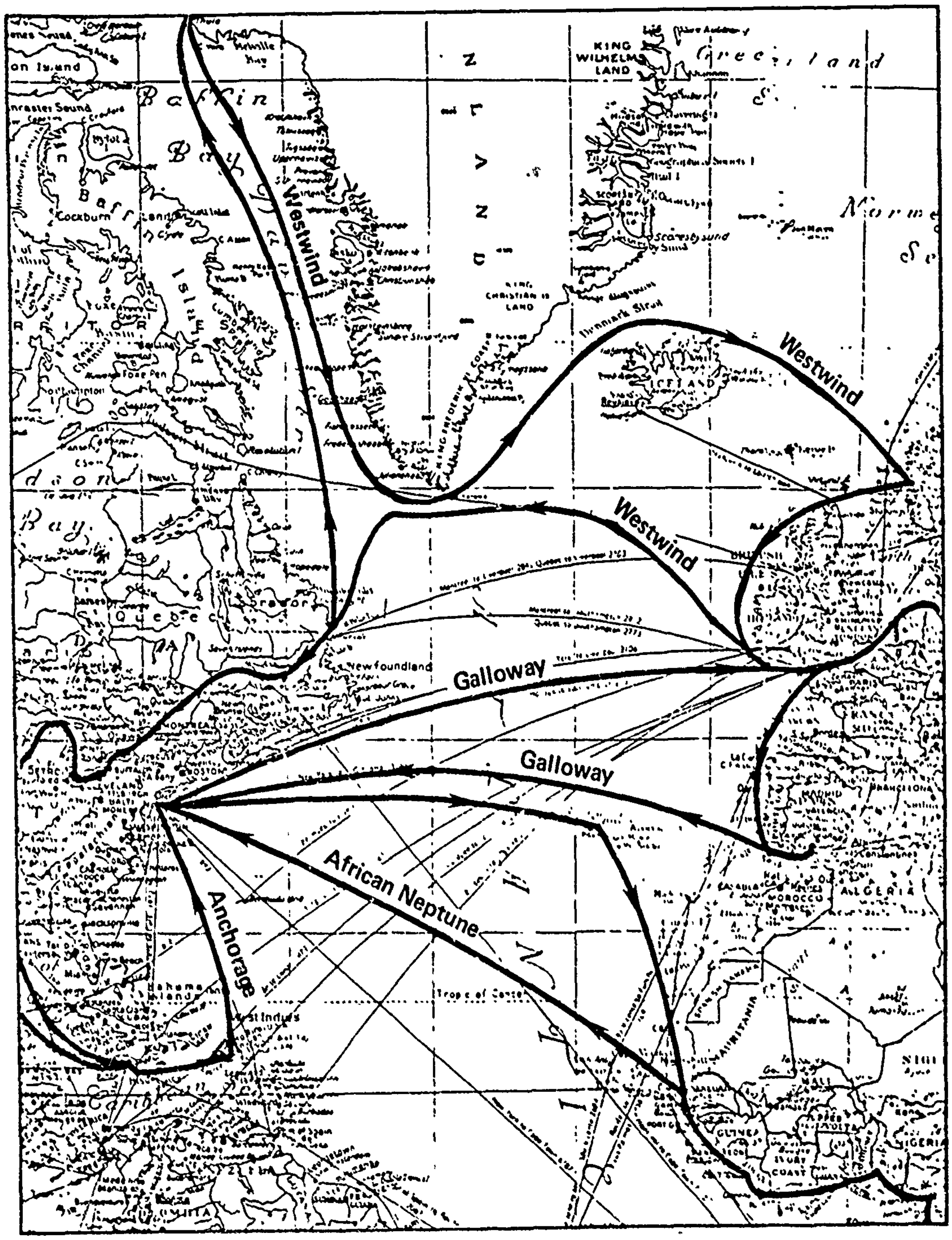


Figure 4-2   North Atlantic MX1102/04 Deployment 1978

A review of these measurements has indicated that the data suitable for processing is limited to July 1978 for the ANCHORAGE, April 1978 for the GALLOWAY and October, November and December 1978 for the AFRICAN NEPTUNE.

For each satellite fix, the following OMEGA data is available: signal phase values and calibrated signal-to-noise ratio index for each signal/station frequency tracked, phase difference values, estimated single station phase errors, estimated lane information, position difference vectors (distance, azimuth) for each LOP combination, and best fix for each frequency.

4.2 TEST DATA

The test data were collected by the Naval Ocean Systems Center (NOSC) through a special data collection effort organized to assess the performance of the OMEGA Navigation System in the Northern Atlantic region. The two basic categories of data were derived from a) 27 aircraft flights between 18 July and 20 September 1978, and b) 12 ground monitoring sites operated at various times between mid-July and October 1978 at selected locations in the North Atlantic region. A more complete report of the NOSC test data collection effort is contained in reference (15).

4.2.1 Airborne Monitor Data

The airborne data were oriented toward validating the transmitting station coverage contours and confirming the areas of modal interference.

A complete list of flights and OMEGA stations monitored is given in Table 4-4. A separate list of radial flight data is given in Table 4-5. The flight itinerary for Flights 1-7 and flights 8-23B is listed in Tables 4-6 and 4-7 respectively. The flight routes are shown in Figures 4-3 and 4-4.

TABLE 4-4

NOSC FLIGHT DATA
SIGNAL AMPLITUDE VS TIME

FLIGHT #	10.2 KHZ							13.6 KHZ							-Frequency
	A	B	C	D	E	F	H	A	B	C	D	E	F	H	-Stations
1								X					X		
2		X						X	X						
3								X							
4	X					X		X					X		
5	X					X		X	X				X		
6	X	X				X		X	X				X		
7	X					X		X	X				X		
8	X							X	X				X		
9	X	X				X		X	X				X		
10	X	X				X		X	X				X		
11	X	X		X				X	X		X				
12	X	X		X		X		X	X				X		
13A	X	X				X		X	X			X			
13B	X	X		X				X	X		X	X			
14A	X	X		X				X	X			X	X		
14B		X							X						
15		X			X				X			X	X		
16		X			X				X			X			
17		X	X	X					X	X	X	X			
18	X	X				X		X	X				X		
19A	X	X				X		X	X		X		X		
19B	X	X				X		X	X		X		X		
20	X			X		X		X	X		X		X		
21	X	X		X				X			X		X		
22	X	X		X				X	X		X	X			
23A	X	X	X					X	X	X					
23B	X	X		X		X		X	X		X		X		

TABLE 4-5

NOSC RADIAL FLIGHT DATA
SIGNAL AMPLITUDE VS RANGE

OMEGA STATION	FLIGHT NO.	
	DAYTIME	NIGHTIME
A. NORWAY	11, 12, 13A, 13B, 14A	8, 18, 19A, 19B, 20
B. LIBERIA	13A, 13B, 14A, 14B, 17	2, 6, 9, 10, 15, 16
D. N. DAKOTA	21	20, 21
F. ARGENTINA		5, 7, 18, 19A, 19B

NOTE: Both 10.2 and 13.6 kHz signals were measured during all listed flights except Nos. 5 and 7. Only 13.6 kHz signals were measured during Flights 5 and 7.

TABLE 4-6

AIRCRAFT FLIGHT ITINERARY (FLTs 1-7)

FLT NO.	ORIGIN			DESTINATION			DURATION HRS	OVERFLIGHT LOCATIONS
	LOCATION	DATE	GMT	LOCATION	DATE	GMT		
1	Atlantic City	Jul 18	0206	San Juan	Jul 18	0512	3.1	NAFEC, Sabana Seca
2	San Juan	Jul 19	0100	Merida	Jul 19	0435	3.6	Sabana Seca
3	Merida	Jul 21	0228	San Juan	Jul 21	0547	3.3	Sabana Seca
4	San Juan	Jul 22	0030	San Juan	Jul 22	0355	3.4	Sabana Seca
5	San Juan	Jul 24	0055	Bermuda	Jul 24	0430	3.6	Sabana Seca
6	Bermuda	Jul 25	0119	Bermuda	Jul 25	0438	3.3	Bermuda
7	Bermuda	Jul 27	0115	Atlantic City	Jul 27	0434	3.3	NAA (Cutler, ME), NAFEC

TABLE 4-7

AIRCRAFT FLIGHT ITINERARY (FLTs 8-23)

FLT NO.	ORIGIN LOCATION	ORIGIN DATE	ORIGIN GMT	DESTINATION LOCATION	DESTINATION DATE	DESTINATION GMT	DURATION HRS	OVERFLIGHT LOCATIONS
8	Atlantic City	Aug 25	0156	Gander	Aug 25	0606	4.1	NAFEC
9	Gander	Aug 26	0030	Azores	Aug 26	0347	3.3	Gander, Villa Nova
10	Azores	Aug 28	2310	Gander	Aug 29	0246	3.6	Villa Nova, Gander
11	Gander	Aug 30	1248	Keflavik	Aug 30	1544	2.9	Keflavik
12	Keflavik	Aug 30	1750	Bodo	Aug 30	2004	2.2	Keflavik, OMEGA 'A'
13A	Bodo	Aug 31	1330	Mildenhall	Aug 31	1550	2.3	OMEGA 'A'
13B	Mildenhall	Sep 2	1125	Rota	Sep 2	1410	2.8	--
14A	Rota	Sep 4	1214	Dakar	Sep 4	1546	3.5	--
14B	Dakar	Sep 4	1738	Monrovia	Sep 4	1906	1.5	OMEGA 'B'
15	Monrovia	Sep 6	2147	Recife	Sep 7	0143	4.0	OMEGA 'B', Monrovia, Natal
16	Recife	Sep 8	2134	Monrovia	Sep 9	0136	4.0	Natal, Monrovia, OMEGA 'B'
17	Monrovia	Sep 10	1134	Cape Verde	Sep 10	1445	3.2	OMEGA 'B'
18	Cape Verde	Sep 12	0010	Azores	Sep 12	0340	3.5	Vila Nova
19A	Azores	Sep 13	2210	Shannon	Sep 14	0112	3.0	Vila Nova
19B	Shannon	Sep 14	2118	Bodo	Sep 14	2350	2.5	OMEGA 'A'
20	Bodo	Sep 16	2134	Sondrestrom	Sep 17	0147	4.2	OMEGA 'A'
21	Sondrestrom	Sep 18	0033	Sondrestrom	Sep 18	0409	3.6	--
22	Sondrestrom	Sep 18	2222	Frobisher	Sep 18	2346	1.4	Frobisher
23A	Frobisher	Sep 19	1856	Gander	Sep 19	2109	2.2	Frobisher
23B	Gander	Sep 19	2227	Atlantic City	Sep 20	0054	2.5	NAFEC

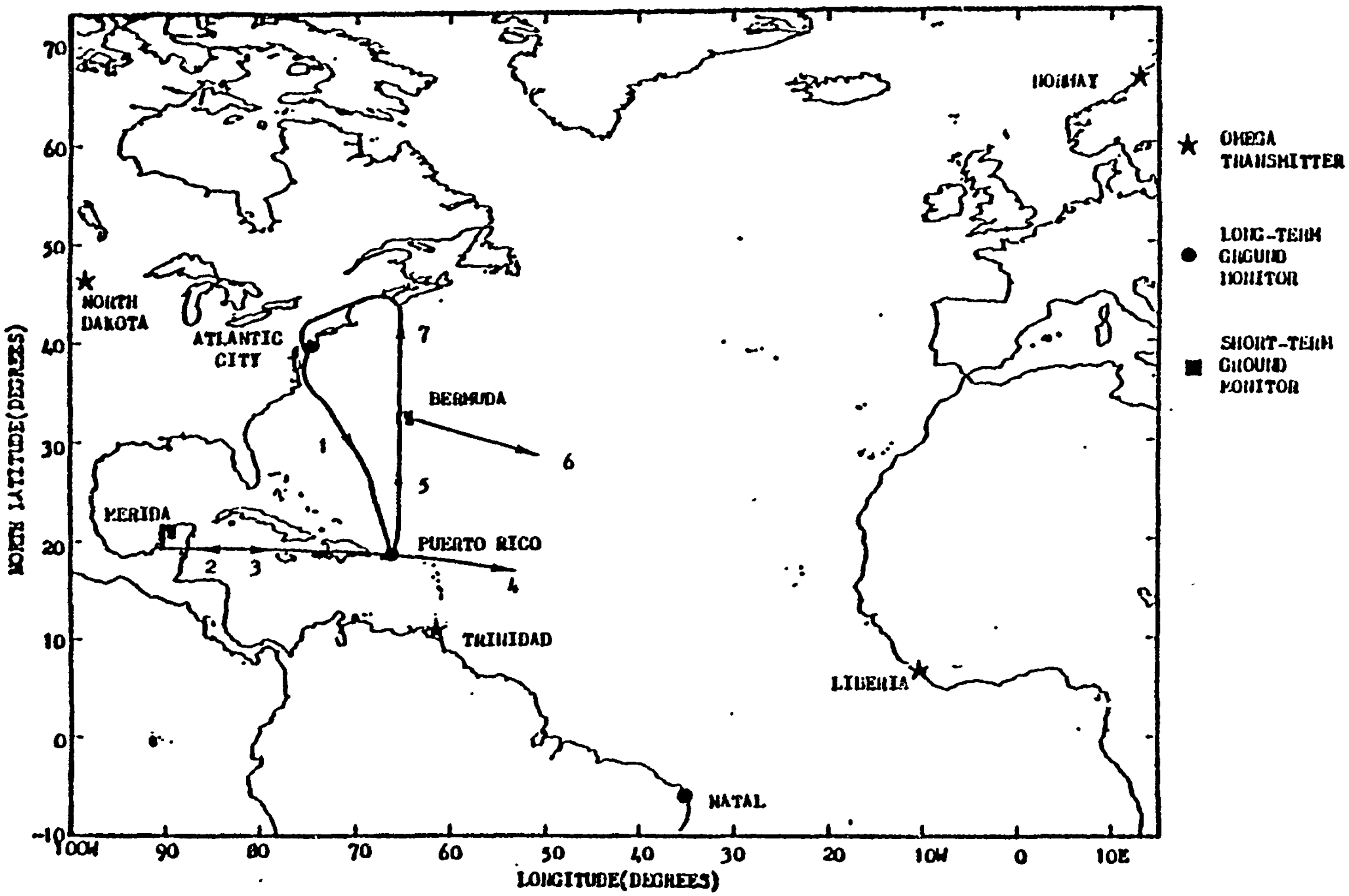


Figure 4-3 Aircraft Flight Paths (FLTs 1-7)

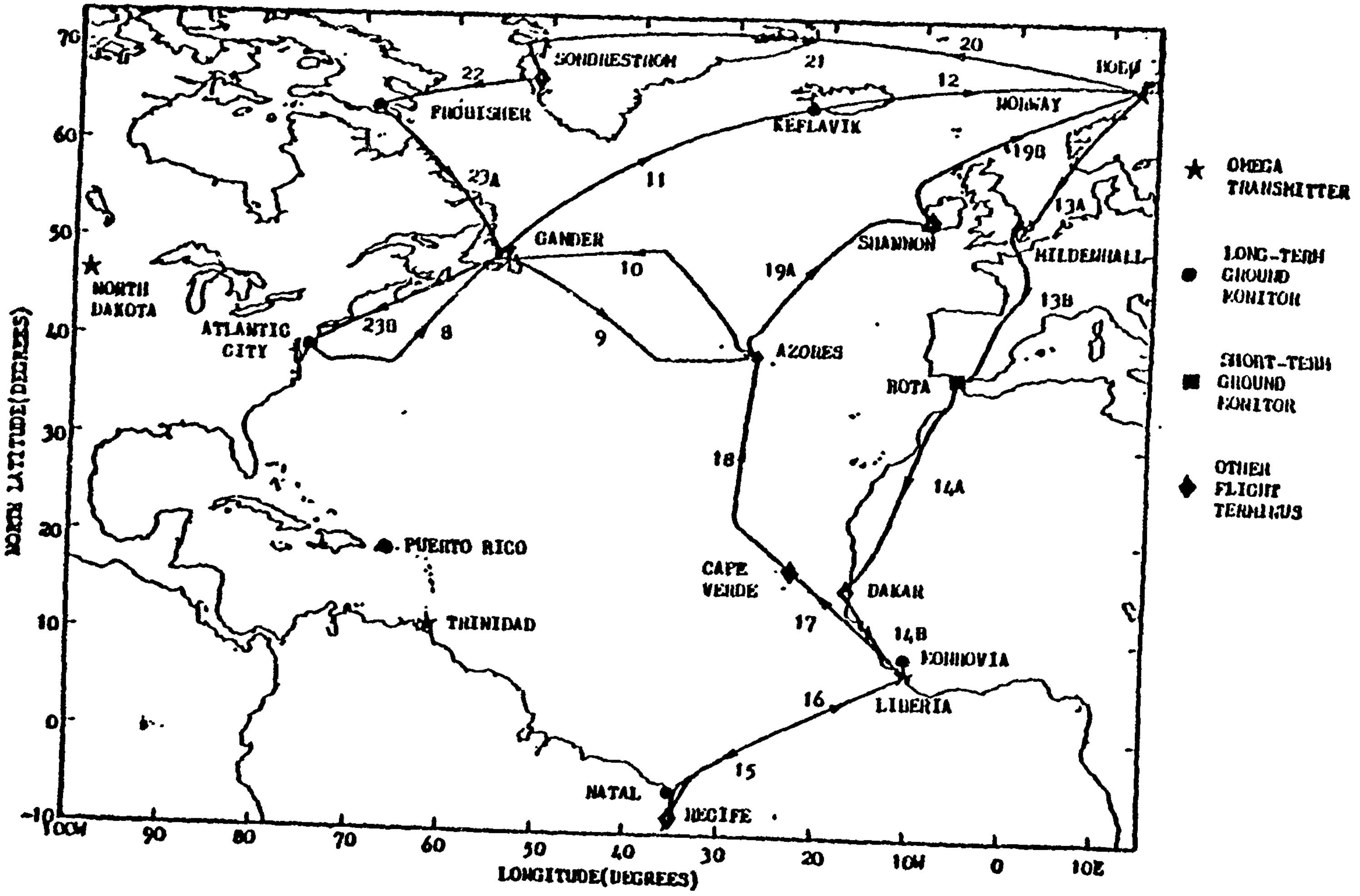


Figure 4-4 Aircraft Flight Paths (FLTs 8-23)

The aircraft flight data are in two forms, a) plots of signal strength (dB > 1μv/m) vs GMT for all flights and b) plots of signal strength vs range from the OMEGA transmitter stations for the radial flights.

4.2.2 Ground Monitor Data

Measurements were made at five long-term ground sites and seven short-term ground sites. A list of the ground monitoring sites, collection dates, and OMEGA stations recorded is given in Tables 4-8 and 4-9 for the long-term and short-term monitor sites, respectively.

The ground station data are in the form of plots of signal strength (dB > 1μv/m) vs GMT. For the long-term monitors, the signal strength plots show average and standard deviation over approximately weekly periods while the short-term monitor data are averaged over somewhat shorter periods.

Noise measurements were made at the ground monitor stations only during those periods when the transmitting station was off-the-air as indicated in Tables 4-8 and 4-9.

TABLE 4-8

INDEX OF PLOTS OF OBSERVED DIURNAL SIGNAL AMPLITUDES
AT LONG-TERM RECEIVER SITES

DATA PERIOD			Atlantic City					Sebana Seca					Natal		Frobisher				Keflavik				
GMT		Julian	A	B	C	E	F	A	B	E	F	N	B	E	A	B	D	F	A	B	D	E	F
JULY	9-16	190-197						X	X		X	X											
	17-23	198-204	X	X	X		X	X	X		X	X	/	X									
	24-31	205-212	X	X	X		X	X	X		X	X	X										
AUGUST	1-8	213-220	N	X	X		X	N	X		X	X	X	X									
	9-16	221-228	X	X	X		X	X	X		X	X											
	17-23	229-235	X	X	X		X	X	X	X	X		X	X	X	X	X	X					
	24-31	236-243	X	X		X	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X
SEPTEMBER	1-8	244-251	X	X		X	X	X	X	X	X		X	X	X	X	X	X	X	X		X	X
	9-15	252-258	X	X		X	X	X	X	X	X		/	/	X	X	X	X	X	X		X	X
	16-22	259-265						X	X	X	X				X	X	X	X	X	X		X	X
	23-30	266-273													X	X	X	X	X	X	X		X

<u>Legend</u>

X - 10.2 & 13.6 KHZ
/ - 10.2 KHZ
N - Noise Only; XMTR Off-Air

TABLE 4-9

INDEX OF PLOTS OF OBSERVED DIURNAL SIGNAL AMPLITUDES AT SHORT-TERM RECEIVER SITES

	A	B	C	D	E	F	H
Lajes, Azores							
Aug. 24-31			X				
Sept. 1-8	X	X		X		X	
24-30					X		
Monrovia, Liberia							
Sept. 5-12	X			X	X	X	
Natal, Brazil							
July 19-23	\						
Aug. 10-14			X				X
14-17	X						
17-23		X				X	
24-31					X		
Merida - No usable data due to high noise levels and uncertainties in absolute field strengths measurements.							
Bermuda							
July 24-26	/	/				/	N
Gander							
Aug 25-29	/	/		/		/	
Rota							
Sept. 3-4	/	/			/	/	
Bodø							
Sept. 15-16			/		/	/	/

X - 10.2 KHZ & 13.6 KHZ
/ - 10.2 KHZ only
\ - 13.6 KHZ only
N - Noise only: XMTR Off-Air

5. CLASSIFICATION AND SYNTHESIS OF DATA

5.1 DATA CATEGORIES

The data base for the North Atlantic OMEGA validation consists of scientific data collected under controlled conditions at OMEGA ground monitor facilities operated by, or in cooperation with ONSOD, and from test data collected by NOSC at ground sites and aboard aircraft. Other scientific data is provided by integrated OMEGA/Satellite shipborne measurements.

The NOSC test data provide both airborne and fixed ground signal amplitude measurements while the ONSOD fixed monitor data basically provide phase difference measurements. However, some of the more recent ONSOD fixed monitor data also provide SNR information.

The integrated OMEGA/Satellite shipborne measurements include SNR indices, and phase difference and position-fix accuracy information.

In addition, a considerable amount of operational data are available from a variety of sources which provide information on SNRs and position-fix accuracy relative to an independent navigation system of allocable accuracy.

5.2 TEST AND NON-TEST DATA INTEGRATION

The NOSC test data are the prime source of information for determining OMEGA signal coverage. Where deficiencies in these data have been found, additional SNR data have been obtained from the ONSOD monitor data file to supplement the NOSC test data. In addition, SNR data for the Norway station were obtained from the integrated OMEGA/Satellite measurements for the Caribbean and Gulf of Mexico. Also, SNR measurements from the airborne operational data have been analyzed to see if these are con-

sistent with the test measurements. In some cases, where NOSC test data deficiencies exist, the airborne operational data have been used to supplement the data base.

The ONSOD ground monitor data were the prime measurements for determining phase difference errors and fix-accuracy errors. The integrated OMEGA/Satellite shipborne measurements were used to supplement these data.

5.3 DATA REDUCTION PHILOSOPHY

The reduction of the data varied with the type of data. The first step was to establish SNRs for each OMEGA transmitting station as a function of geographic location. To accomplish this, the NOSC 10.2 kHz and 13.6 kHz amplitude data were scaled to establish signal levels around local noon and midnight. Both the fixed ground site and aircraft data were used and the amplitude values were tabulated.

Next, noise levels in a 100 Hz bandwidth at 10.2 kHz and 13.6 kHz were derived from CCIR[16]. Although noise data measured aboard the test aircraft in-flight were supplied by NOSC, these noise measurements were very sparse. A comparison of these values with CCIR values indicated fairly good agreement. Therefore, because there were so few noise measurements, the decision was made to use CCIR values throughout the data reduction process.

From the test amplitude measurements and the CCIR noise levels, SNRs were derived and tabulated for each OMEGA station as a function of season, time of day, and geographic location. These values of SNR were then placed on individual maps of the North Atlantic region. To supplement these values of SNR, additional data were acquired from the ONSOD monitor sites where the Magnavox 1104 receivers are used. These data were in the form of SNR indices and required conversion to decibels using a calibration curve. This calibration curve is extremely steep and errors in conversion could amount to a few decibels. In addition, further

supplementary data were acquired from the integrated OMEGA/Satellite measurements and some of the user aircraft data. These also were in the form of SNR indices and required conversion to decibels using the appropriate calibration curves.

After all the SNR values had been placed on the individual diagrams, coverage contours were drawn. These contours were drawn to reflect areas which likely would not be affected by near-field phenomena or modal interference, and areas where the SNR was >-20dB. Next, the individual contours were overlaid to produce composite coverage diagrams for summer and winter, day and night at 10.2 kHz to compare with theoretical predictions. The 13.6 kHz data were analyzed to reveal differences in coverages between 10.2 kHz and 13.6 kHz signals.

The ONSOD ground monitor station data have been processed on a Honeywell 6000 computer using the U.S. Coast Guard EVAL program[17] which, among other things, calculates the average and standard deviation of the predicted phase difference error for each hour, each day of the month for LOPs of interest.

In processing these data to assess fix-accuracy, both unflagged monthly data blocks and monthly data blocks flagged S, Q, B, and E were used. Data blocks flagged F were not used.

Within each data block there are also daily/hourly flags (i.e. SID, PCA, transmitter out, monitor out, etc.). These flagged data were not used in the fix-accuracy calculations.

These data have been further processed to find the average of the fix bias error and standard deviation of radial error about the bias point over two five-hour periods, centered at local noon and local midnight. From these data, the months to be combined to calculate OMEGA fix accuracies for summer and winter, day and night as a function of LOP pairs were selected. The winter months selected were restricted to December/January/February and the summer months to June/July/August. The number of months selected varied from site-to-site and season-to season. The maximum number of months used for a site/season was seven and the

minimum was one. Emphasis was placed on the more recent data and those times when several LOPs were being measured. It should be pointed out however, that a review of the total data base showed good consistency in the phase measurements over the span of years of data collection and different types of receivers.

These data were then processed on a Honeywell 6000 computer using the U.S. Coast Guard accuracy program. All possible combinations of LOP pairs were processed. The output from the computer program resulted in fix bias error, standard deviation of radial error about the bias point and total fix error. These statistics were then tabulated for each monitor site, summer/winter, and day/night. Following this, the resultant tables were edited to delete any LOP pair combination containing signals from any OMEGA transmitting station which the earlier coverage analysis indicated no coverage.

In addition, the MX1102/1104 integrated OMEGA/Satellite shipboard measurements have been processed on the Data General Eclipse S-200 minicomputer at the Coast Guard facilities in Washington, D.C. to determine OMEGA fix accuracies.

The MX1102/1104 OMEGA/Satellite monitor provides data output in the form of cassette tapes with the following information given at the time of closest approach of the NAVSAT satellite[18]:

a) GMT of the satellite fix

b) coordinates of the satellite fix

c) date and GMT of OMEGA monitor data

d) dead reckoning position coordinates

e) letter designations of OMEGA station monitored

f) designation of channel used for calibration

g) phase measurements relative to an internal oscillator at 10.2 kHz, 11.3 kHz and 13.6 kHz for each OMEGA station

h) signal-to-noise ratio measurements at 10.2 kHz, 11.3 kHz, and 13.6 kHz for each OMEGA station.

A computer program was developed by Magnavox personnel to examine the above data and provide the following information whenever a satellite fix was found in the data tape:

a) date and time of the satellite fix

b) phase and SNR of each station at each frequency

c) coordinates and time of closest approach for the satellite fix

d) theoretical range to stations with SNR greater than -20 dB

e) skywave corrections for each station at each frequency at which there was good data

f) laning information for those stations which give good data at all three frequencies

g) estimated single station phase errors for those stations which had good data

h) line of position (LOP) errors for each frequency using stations with good data

i) OMEGA fix error calculations using the satellite fix as a reference for all possible combinations of stations and frequencies

j) calculation of "best fix" at each frequency.

6. DATA ANALYSIS

The NOSC test data, the ONSOD ground station data and the integrated OMEGA/Satellite shipboard data have been processed and the results analyzed to show the coverage and accuracy being provided by the OMEGA Navigation System in the North Atlantic oceanic region.

6.1 OMEGA COVERAGE IN THE NORTH ATLANTIC

A detailed analysis of the 10.2 kHz coverage being provided by the OMEGA system has been performed for comparison with predictions (See Figures 3-1 and 3-2 earlier in this report). Similar predictions have not been made for 13.6 kHz and therefore a more qualitative coverage analysis has been performed at this higher OMEGA frequency.

6.1.1 10.2 kHz Coverage

Composite OMEGA 10.2 kHz signal coverage diagrams (Figures 6-1, 2, 3, and 4) have been produced employing the same criteria used for the predicted signal coverage diagrams as follows:

- Areas likely to be affected by near-field phenomena (i.e., areas close ($\sim$1Mm) to transmitting stations) were rejected.
- Areas likely to be affected by modal interference phenomena were rejected.
- Areas with S/N < -20 dB in a 100 Hz bandwidth (based on atmospheric noise models) were rejected.

The modal and near-field areas result in a hard boundary in terms of coverage whereas the SNR threshold is a function of receiver design and is considered a soft boundary. The SNR (100 Hz) criteria of -20dB was originally selected based on the design of marine receivers in existance at the time. This SNR threshold will vary with different types of receivers. However, because it was used for the theoretical predictions of OMEGA 10.2 kHz coverage, it has been retained for the validation process.

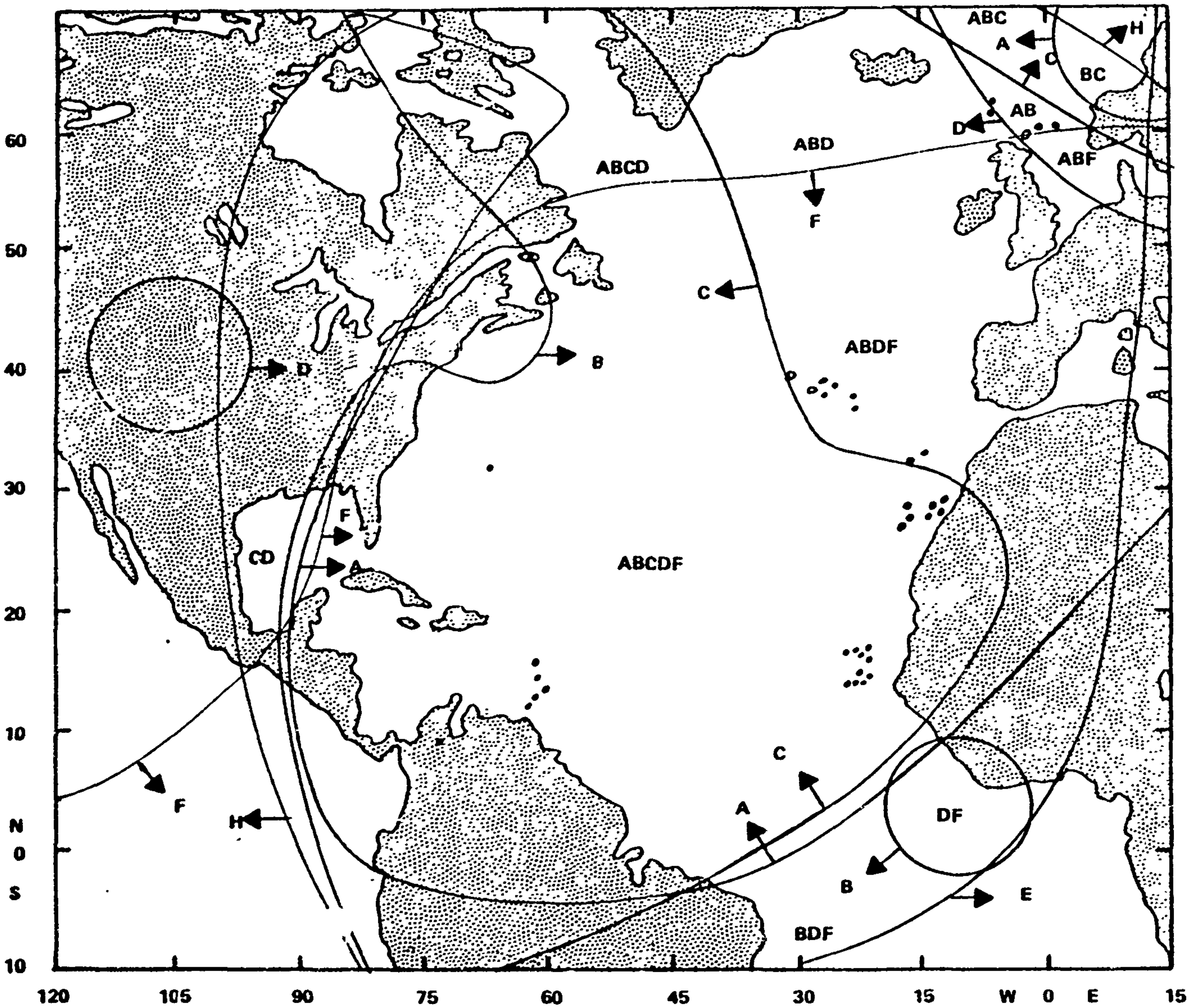


Figure 6-1 Measured Composite Co[illegible]ge Diagram for Local Summer Noon - 10.2 KHz

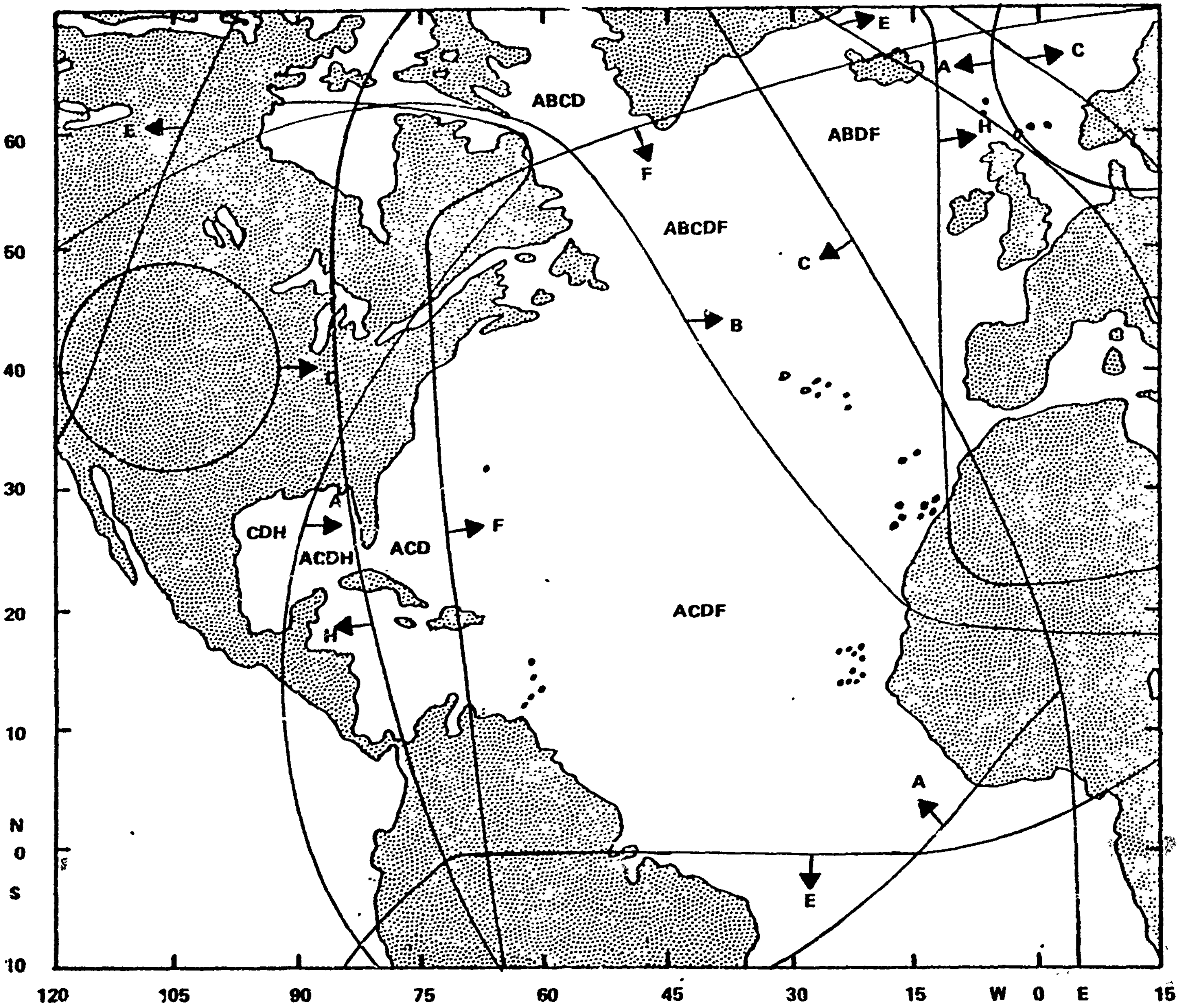


Figure 6-2 Measured Composite Coverage Diagram for Local Summer Night - 10.2 kHz

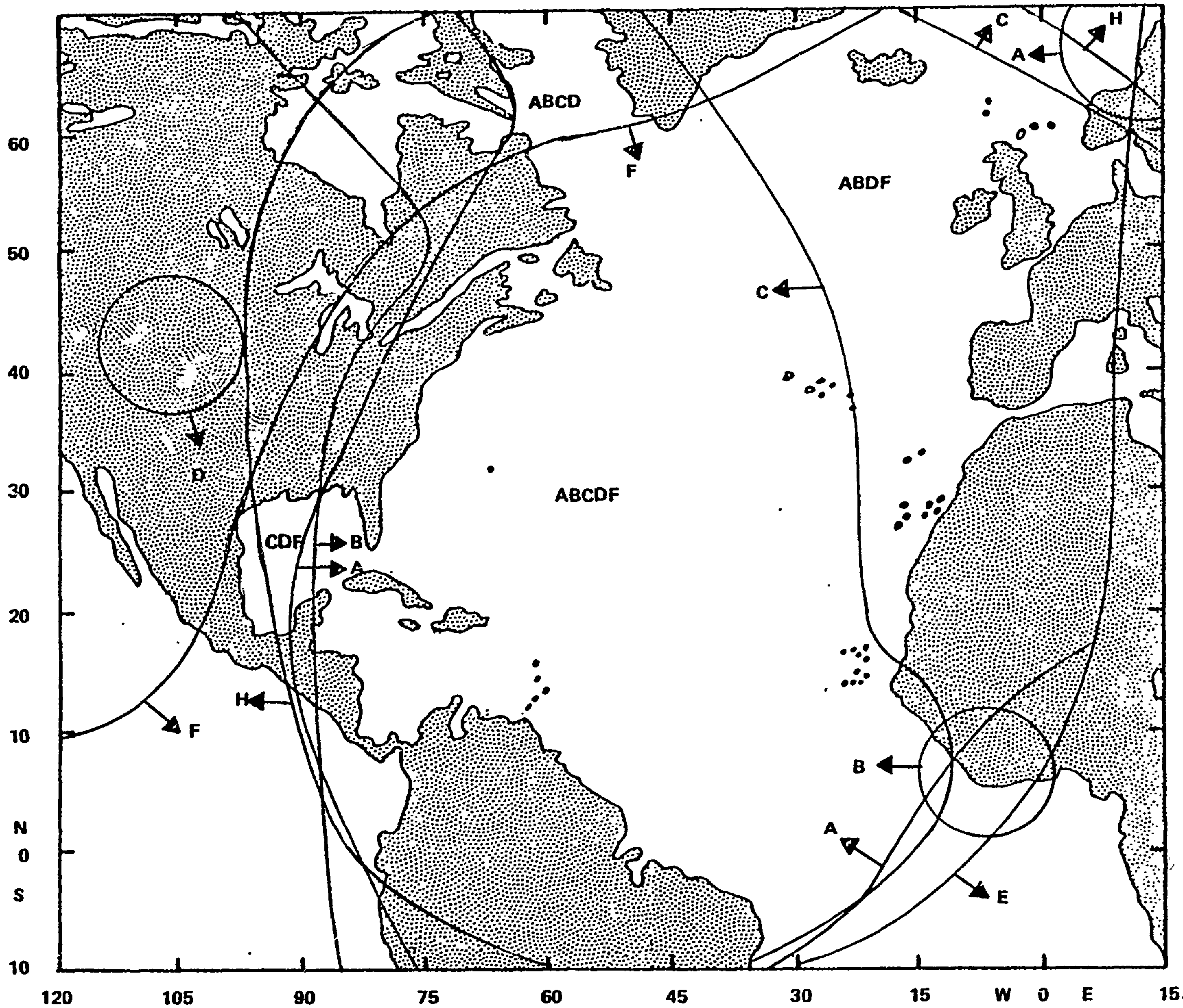


Figure 6-3 Measured Composite Coverage Diagram for Local Winter Noon – 10.2 kHz

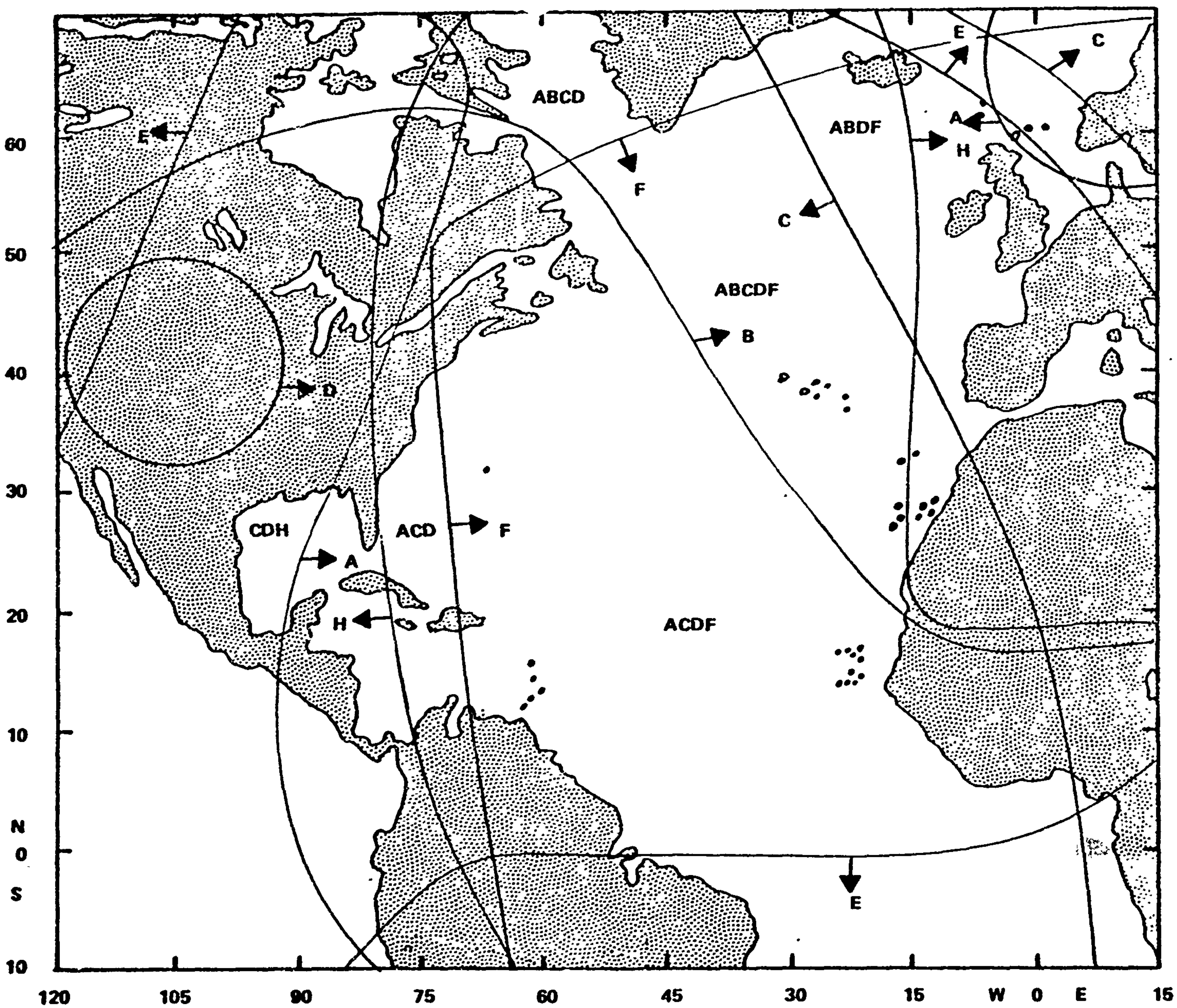


Figure 6-4 Measured Composite Coverage Diagram for Local Winter Night - 10.2 kHz

First, individual maps showing values of SNR were produced for each OMEGA transmitting station, summer and winter, day and night. These are in Appendix C. The majority of the values of SNR were derived from the NOSC signal test data in combination with CCIR noise values. Some additional values were obtained from the ONSOD data file and, in the more northern latitudes (> 60°N), from operational aircraft data.

In most cases it was possible to draw contours of coverage based on a SNR = -20dB, and predicted modal interference and near-field areas. Very few signal measurements from the OMEGA transmitting stations at La Reunion (E) and Japan (H) were made during the NOSC test data collection but they confirmed predictions and therefore the predicted contours were used. Station E was recorded during flights 15 and 16 only between Recife, Brazil and Monrovia, Liberia. These were nighttime flights and the data indicated modal interference. La Reunion signals at Atlantic City, N.J. and Sabana Seca, P.R. were similar and indicated long path propagation during short-path daytime.

The Japan OMEGA transmitting station signal was not recorded during any of the NOSC test flights. Measurements at a few ground sites and onboard operational aircraft indicated poor coverage in the North Atlantic, as expected.

The accessibility of the OMEGA 10.2 kHz signals in the North Atlantic can be summarized as follows:

> Norway (A): The Norway 10.2 kHz signal is accessible to most of the North Atlantic with the exception of the western part of the Gulf of Mexico at all times and a small portion of Baffin Bay during summer day.
>
> Liberia (B): The 10.2 kHz signal from Liberia covers most of the North Atlantic during the day except for a small region of the Northeast coast of the U.S. and Nova Scotia during the summer. At night, both summer and winter, the 10.2 kHz Liberian signal is usable only Northeastward of a (great circle) line from Dakar to Frobisher Bay.

Hawaii (C): During the day, the Hawaii 10.2 kHz signal is excluded in the following regions: (1) east of 40°W Longitude and north of 30°N. Latitude during the summer and 2) east of 25°W. Longitude and North of 15°N. Latitude during the winter, except for a small region in the Norwegian Sea. At night, both summer and winter, the Hawaii signal is excluded east of a line from Southeastern Greenland to Morocco except for a small region in the Norwegian Sea.

North Dakota (D): The North Dakota 10.2 kHz signal covers all points in the North Atlantic, day and night, except for a small portion in the extreme Northeastern Atlantic during summer day.

La Reunion (E): 10.2 kHz signals from La Reunion are mostly "long-path" to points in the North Atlantic, especially during short-path day. In those regions where the long-path signal is blocked by the low conductivity in Greenland, the nighttime signals are modally disturbed and the daytime signals are highly attenuated.

Argentina (F): Daytime 10.2 kHz signals from Argentina are accessible to points in the North Atlantic up to 50°N. Latitude during the summer and 60°N. Latitude during the winter. The western part of the Gulf of Mexico is excluded during summer day. At night, Argentina coverage is excluded only west of about 70°W. Longitude due to modal interference.

Japan (H): The 10.2 kHz Japan signal is generally unavailable in the North Atlantic during the day except for the western part of the Gulf of Mexico in the winter and in the extreme Northeastern region of the North Atlantic. At night, the Japan signal covers regions west of about 75°W. Longitude and east of about 15°W. Longitude. In addition some long-path propagation may occur near the equator.

6.1.2 13.6 kHz Coverage

Composite OMEGA 13.6 kHz coverage diagrams for summer day and winter night are given in Figures 6-5 and 6-6. A comparison of the 13.6 kHz coverage with the 10.2 kHz coverage has indicated the following:

Nowway (A): The Norway 13.6 kHz signal is accessible in Baffin Bay and the Gulf of Guinea during summer day in contrast to the 10.2 kHz signal. Accessibility of

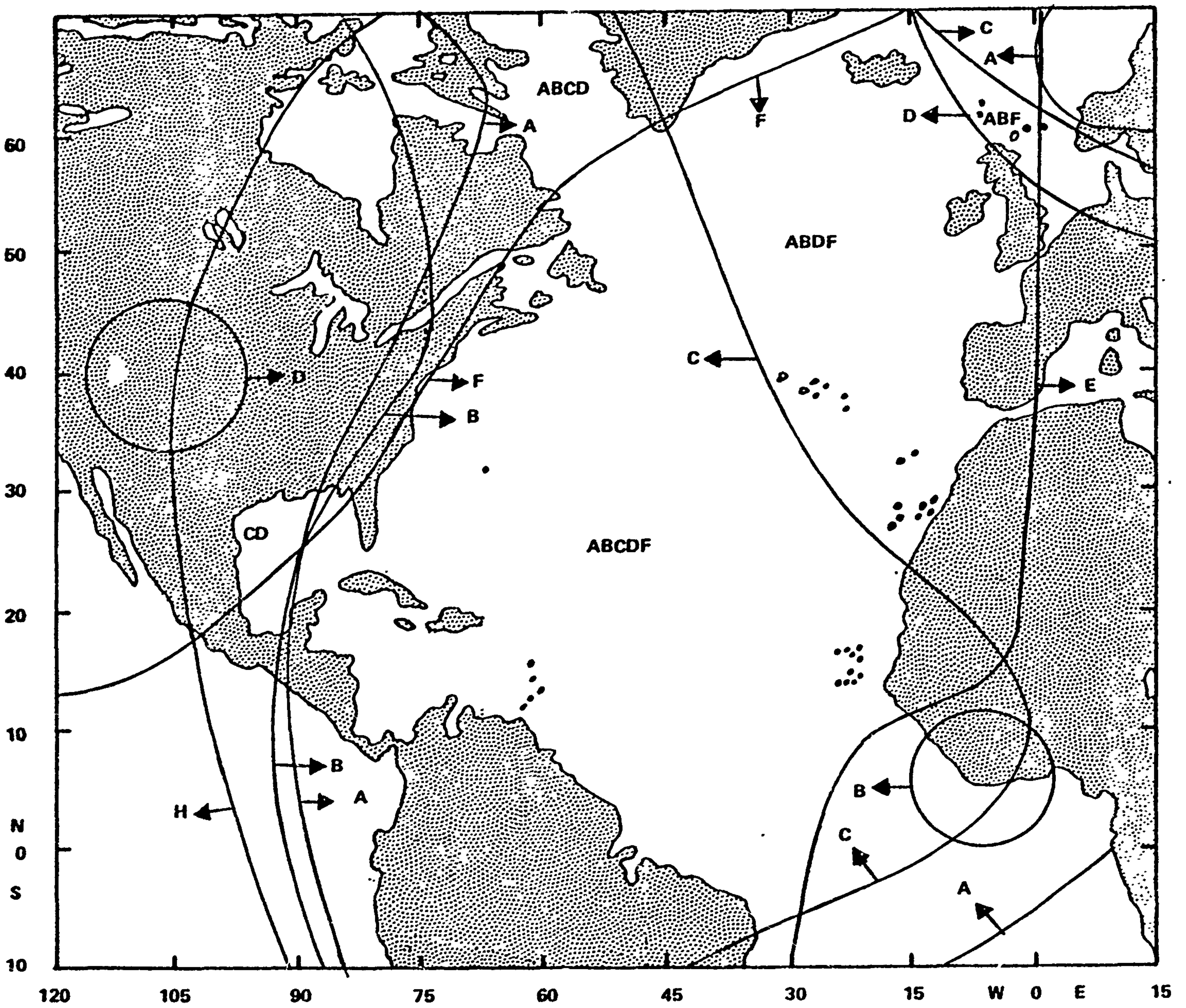


Figure 6-5 Measured Composite Coverage Diagram for Local Summer Noon – 13.6 kHz

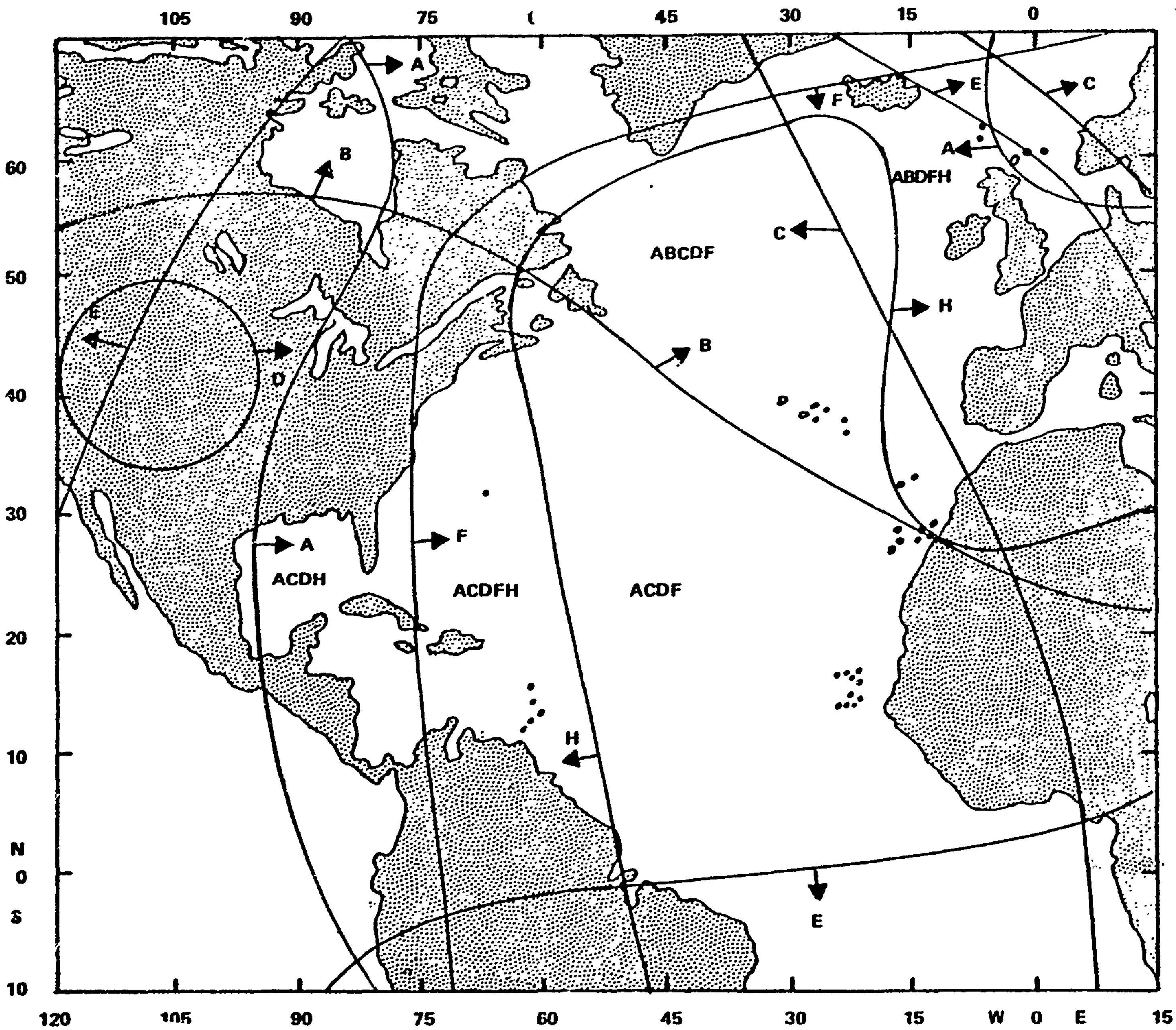


Figure 6-6 Measured Composite Coverage Diagram for Local Winter Night — 13.6 kHz

the 13.6 kHz signal in the Gulf of Mexico is comparable to 10.2 kHz during summer day and slightly better during winter night.

Liberia (B): During summer day, the Liberia 13.6 kHz signal is accessible along the Northeast coast of the U.S. and Nova Scotia in contrast to the 10.2 kHz signal. During winter night, the 13.6 kHz signal provides a few degrees wider coverage on the east coast of Canada and a few degrees less coverage on the west coast of Africa than the 10.2 kHz signal.

Hawaii (C): The Hawaii 13.6 kHz signal is accessible in about the same regions of the North Atlantic as the 10.2 kHz signal.

North Dakota (D): The North Dakota 13.6 kHz signal is accessible in about the same regions of the North Atlantic as the 10.2 kHz signal.

La Reunion (E): The 13.6 kHz signal from La Reunion provides better coverage of the Gulf of Guinea during summer day than the 10.2 kHz signal. During winter night, the coverage provided by the 13.6 kHz and 10.2 kHz signals is similar.

Argentina (F): The Argentina 13.6 kHz signal provides better coverage of the Northeast sector between Greenland and Norway than the 10.2 kHz signal during summer day. The nighttime modal boundary for 13.6 kHz lies slightly further to the west than the 10.2 kHz modal boundary.

Japan (H): During summer day, the Japan 13.6 kHz and 10.2 kHz signals provide similar coverage. During winter night, the 13.6 kHz signal provides better coverage west of 50°W. Longitude and north of 60°N. Latitude than the 10.2 kHz signal.

6.2 10.2 kHz FIX ACCURACY

The accuracies being provided by the OMEGA Navigation System in the North Atlantic were evaluated using data derived primarily from the ONSOD ground monitor stations and the integrated OMEGA/Satellite shipboard installations.

6.2.1 ONSOD Ground Monitor Station Data

OMEGA data have been collected and recorded at many ground facilities over varying periods of time. Table 6-1 lists the facilities which have collected data for at least two lines-of-position (LOP) where phase differences are recorded and at least three OMEGA stations where single station phase is recorded. In some instances there are several years of data and in others, only a month or two.

These data have been processed using the U.S. Coast Guard EVAL[17] program which, among other things, calculates the average and standard deviation of the predicted phase difference error for each hour (24) of each month for LOPs of interest. A sample of the EVAL block print output is given in Figure 6-7. The lines for the average error (bias error) and the standard deviation (random error) are noted.

These data have been further processed to find the average of the fix bias error and standard deviation of radial error about the bias point over two five-hour periods, centered at local noon and local midnight. From these data, months were selected and combined to calculate accuracies for summer and winter, day and night as a function of LOP pairs. All possible combinations of LOP pairs were evaluated and the data were later edited to retain valid data, i.e. LOPs for OMEGA stations providing coverage.

The various error measures [19] of interest are defined in the following paragraphs.

TABLE 6-1

ONSOD GROUND MONITOR FACILITIES

Phase Differences
Belem, Brazil
Bermuda, U.K.
Cambridge, MA
Eglin AFB, FLA
Farnborough, U.K.
Frobisher Bay, Canada
Keflavik, Iceland
Lajes, Azores
Nea Makri, Greece
Panama, Canal Zone
Portsmouth, VA
Sabana Seca, P.R.
Sardinia, Italy
St. Anthony, Newfoundland
TASC, Reading, MA
Vila Nova, Azores
Washington, D.C.
Single Station Phase
Hestmona, Norway
La Moure, N.D.
Monrovia, Liberia
Piarco, Trinidad

1 OBSERVED PHASE DIFFERENCE (CECS) 10.2 KHZ HESTMONA, NORWAY 66.5203 12.8453 C=I( ) APR 71 -0.196 9.999

DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	NITE N	NITE AV	NITE SD
01 APR 71	01	97	015	12	20	56	078	81	86	98	99	98	96	92	66	098	52	813	304	98	86	89	89	M	0	0.	0.
02 APR 71	85	77	75	74	094	013	029	80	50	62	70	68	74	68	45	20	25	19	28	90	01	09	88	65	0	0.	0.
03 APR 71	075	68	71	75	003	34	4C	49	56	69	83	M	71	66	56	30	16	26	16	17	01	04	96	86	0	0.	0.
04 APR 71	802	882	90	94	19	37	49	73	53	65	66	67	60	70	73	49	30	27	28	25	12	08	03	01	0	0.	0.
05 APR 71	89	84	85	01	22	45	55	59	70	80	35	94	88	85	74	30	41	29	21	12	21	017	17	06	0	0.	0.
06 APR 71	96	98	07	17	057	55	071	75	86	891	67	70	67	847	020	002	000	088	092	93	97	063	073	060	0	0.	0.
07 APR 71	048	050	045	055	072	001	016	025	034	049	050	050	052	52	45	15	15	11	085	96	03	91	078	060	0	0.	0.
08 APR 71	057	060	060	064	090	011	028	39	43	059	59	37	054	53	52	44	45	049	048	050	082	95	85	82	0	0.	0.
09 APR 71	070	M	75	87	006	36	49	59	66	74	69	72	69	66	55	19	16	11	07	99	99	05	71	81	0	0.	0.
10 APR 71	89	93	89	05	23	48	57	69	80	94	92	84	81	79	67	34	34	19	16	09	24	00	95	95	0	0.	0.
11 APR 71	98	93	00	13	25	54	64	60	89	00	02	99	004	83	73	36	16	20	14	17	02	04	10	96	0	0.	0.
12 APR 71	00	M	97	04	30	51	68	75	86	95	98	89	82	81	73	48	36	18	092	086	M	08	10	96	0	0.	0.
13 APR 71	92	88	92	04	24	41	61	76	88	97	94	88	001	89	M	M	M	27	18	15	16	04	96	07	0	0.	0.
14 APR 71	98	92	86	96	12	37	49	68	85	82	82	81	81	66	65	54	51	18	036	12	07	06	802	896	0	0.	0.
15 APR 71	97	95	03	08	26	44	48	62	66	86	M	84	82	90	74	49	38	22	11	08	16	96	18	04	0	0.	0.
16 APR 71	97	89	00	14	26	55	65	72	85	90	94	97	88	86	64	32	29	28	14	04	98	10	07	91	0	0.	0.
17 APR 71	00	91	95	08	27	47	54	68	73	80	84	92	86	77	66	43	39	30	18	06	08	06	16	97	0	0.	0.
18 APR 71	82	80	84	04	19	39	47	54	71	71	81	79	76	78	60	23	51	829	22	24	18	08	04	03	0	0.	0.
19 APR 71	96	M	89	04	22	M	53	60	75	89	88	91	M	82	M	38	39	22	12	17	00	810	10	01	0	0.	0.
20 APR 71	893	890	98	17	17	832	50	M	85	88	92	91	86	81	70	31	30	036	27	896	812	90	070	059	0	0.	0.
21 APR 71	047	046	054	070	082	008	008	32	45	61	58	57	055	49	35	07	006	05	896	891	801	890	893	877	0	0.	0.
22 APR 71	071	68	71	077	094	24	33	30	48	65	62	58	62	46	826	06	804	802	095	94	85	877	872	862	0	0.	0.
23 APR 71	065	055	056	074	095	820	37	44	57	65	68	66	63	56	842	21	24	16	11	99	803	99	88	91	0	0.	0.
24 APR 71	78	81	84	96	13	30	38	45	53	65	67	68	68	64	48	28	28	23	13	12	08	98	06	89	0	0.	0.
25 APR 71	86	72	84	94	12	30	36	48	62	70	75	78	71	71	50	38	27	28	17	09	11	M	99	00	0	0.	0.
26 APR 71	94	88	91	97	07	27	48	51	70	78	75	75	75	67	41	13	43	27	16	22	M	M	02	01	0	0.	0.
27 APR 71	94	95	95	10	23	42	52	61	84	91	81	84	86	76	56	32	31	30	19	09	809	98	804	804	0	0.	0.
28 APR 71	86	82	85	06	18	37	48	61	84	88	91	88	86	74	49	32	30	27	25	04	08	00	91	90	0	0.	0.
29 APR 71	80	78	77	92	008	32	53	62	65	78	77	74	78	73	45	14	19	21	10	03	86	92	00	92	0	0.	0.
30 APR 71	76	78	72	03	08	35	46	57	73	80	83	M	71	64	46	27	32	21	06	08	06	07	05	04	0	0.	0.

GMT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
D	21	21	25	25	20	25	24	28	29	27	28	27	24	29	25	27	26	24	22	26	23	23	23	22	
	-8.8	-14.7	-12.2	1.6	20.4	40.5	50.3	57.3	69.9	80.4	80.1	79.6	77.3	71.9	57.7	30.5	31.2	21.9	16.7	7.8	4.8	1.3	1.1	-4.6	
	7.2	9.3	10.1	11.4	5.9	8.5	8.4	18.0	14.3	11.5	12.2	12.5	9.0	18.2	10.4	12.7	10.2	7.6	6.3	9.5	10.3	6.4	9.6	7.6	
	15.1	14.4	15.8	17.8	16.8	14.3	15.1	13.6	15.5	13.3	13.3	13.5	12.9	12.9	14.4	14.7	12.9	10.9	13.2	13.9	10.5	10.9	12.8	14.2	
BNC	34	35	33	26	-6	-18	-37	-33	-40	-49	-47	-45	-46	-39	-26	10	6	1	9	13	17	22	28	33	
	36	35	33	18	-1	-14	-34	-29	-39	-45	-44	-44	-43	-33	-16	11	7	7	8	15	19	22	28	34	
RMS	16.3	17.7	18.1	19.0	21.5	15.8	15.5	13.7	15.9	14.6	15.3	15.8	14.4	15.9	16.6	10.7	15.4	11.0	13.7	14.5	11.1	11.8	12.8	14.5	— AVERAGE
	-0.4	5.5	5.0	4.2	9.0	1.3	1.0	-1.0	-4.6	-7.6	-8.8	-9.3	-7.0	-10.1	-10.9	-15.2	-11.9	-0.1	0.6	4.0	3.0	2.5	-3.3	-2.6	
	6.8	8.6	10.0	10.8	9.9	8.2	8.1	11.8	14.2	11.5	12.2	12.5	8.9	12.1	10.4	11.7	10.2	6.3	6.2	9.4	10.2	6.4	9.5	7.6	— STD. DEV.

GROUPED RMS AND S.D. (UNFLAGGED)

	RMS	N	SD	RMS	N	SD
DAY	11.00	30	10.04	7.62	24	7.62
NITE	0.	0	0.	0.	0	0.
TRANS	15.85	672	14.11	12.26	568	10.34
24HRS	15.67	702	13.99	12.10	592	10.24

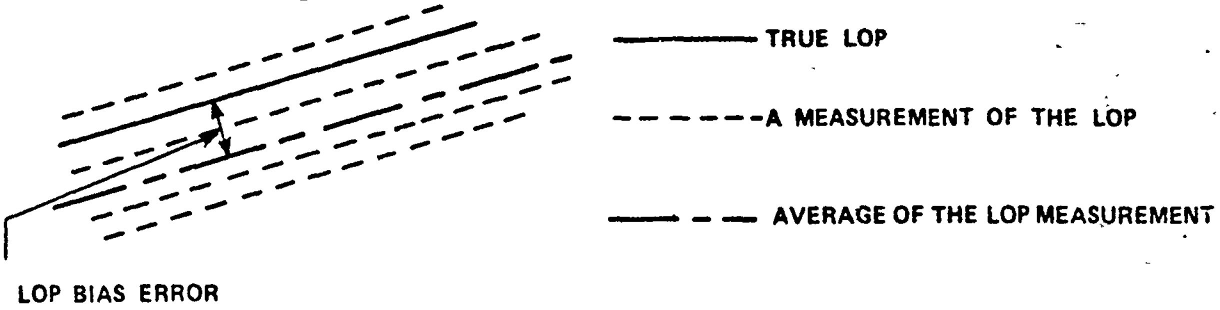
SID/PCA/UAN(S/P/U)	4.4	PCT
XMTTR OUT(T)	0.	PCT
MON OUT(M)	2.5	PCT
NUM/SD(L)	0.	PCT
OUTLIERS(U)	10.8	PCT
TOTAL ERROR	17.8	PCT

NIGHT NB 0 AVERAGE = 0.
DAY NB 24 ADJUSTED AV = 1057.062
AVERAGE ADJUSTMENT = 0.158

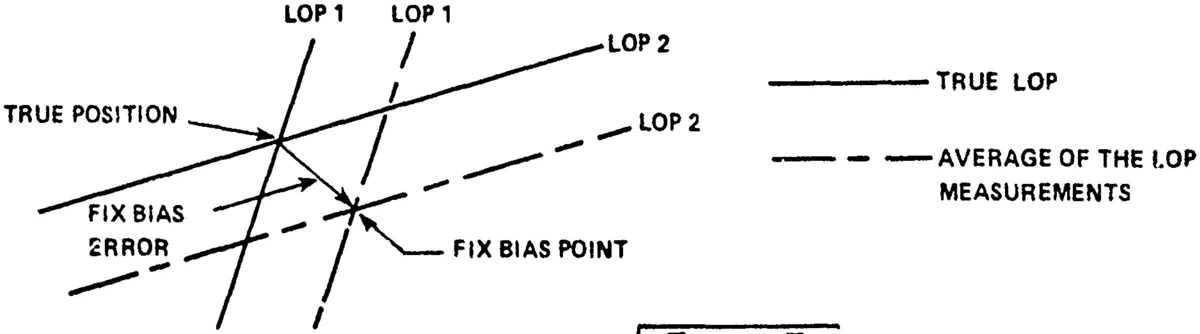
LOP = 1057.2580 D = -0.197

Figure 6-7 Sample of EVAL Block Print

1. <u>LOP bias error:</u> The average (mean) value of a set of measurements of a given LOP.



2. <u>Fix bias error:</u> The distance between the true position and the intersection of two average measured LOP's (see 1 above). This intersection is known as the fix bias point. This bias error is almost entirely due to PPC error.



<u>Calculation:</u> Fix Bias Error $= \sqrt{(\overline{\Delta x})2 + (\overline{\Delta y})2} = R$

and $\overline{\Delta x} = \frac{1}{N} \sum_{i=1}^{N} \Delta x_i$; $\overline{\Delta y} = \frac{1}{N} \sum_{i=1}^{N} \Delta y_i$

where Δy_i = North-South component of i^{th} measurement of fix error

Δx_i = East-West component of i^{th} measurement of fix error

3. <u>Standard deviation of radial error about bias point:</u> The standard deviation of the distance between the bias point (see 2 above) and the measured fix points. This error measure indicates the "stability" of the fix, i.e., the "random" component of the error.

Calculation: Std. dev. of Radial error = σ_r

$$= \frac{\lambda\sigma_\phi}{2 \sin \theta}\left[\frac{1}{\sin^2\phi_1/2} + \frac{1}{\sin^2\phi_2/2} - \frac{2\rho\cos\theta}{\sin \phi_1/2 \ \sin \phi_2/2}\right]^{1/2}$$

where λ = wavelength (nm)

σ_ϕ = standard deviation of LOP phase error

θ = LOP crossing angle

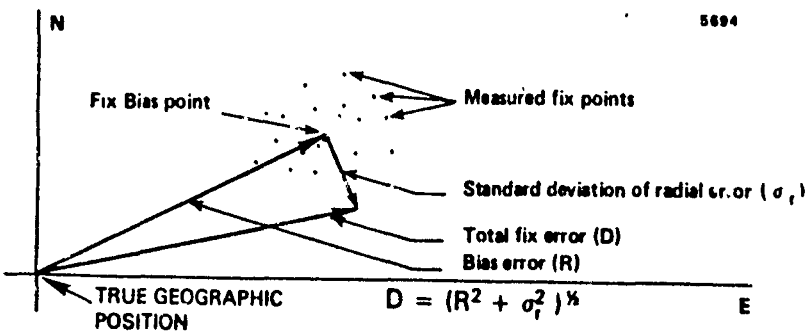
ϕ_i = angle subtended by two transmitting stations comprising the i^{th} LOP

ρ = correlation coefficient

= -0.5 for three stations

= 0 for four stations

4. Total fix error: The root-mean-square of the distance between the true fix point and the measured fix point. This error measure indicates the total error due to both bias error and random error sources. The actual error distribution is approximated by a circular bivariate Gaussian error distribution.



Calculation:

$$\text{Total Fix Error} = \left[R^2 + \sigma_r^2\right]^{1/2}$$

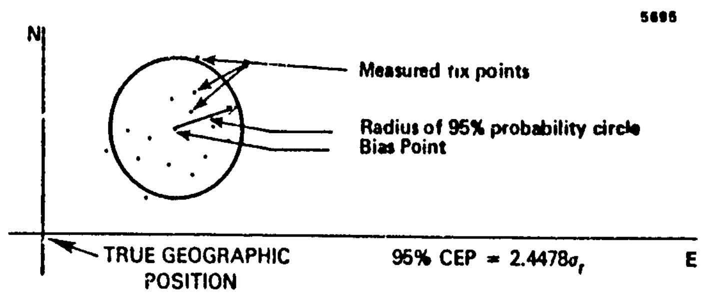
where R = Fix bias error

σ_r = Std. Dev. of radial error

Error distribution: $p(r,\theta) = \dfrac{1}{2\pi\ \sigma_r^2} e^{-r^2/2\sigma_r^2}$

where r, θ = distance, angle about bias point

5. Radius of 95% probability circle: The radius of the circle, centered at the bias point which encloses 95% of all fix measurements.



Calculation: Solution of $\int_0^{R(0.95)} p(r,\theta)\, r\,dr\,d\theta = 0.95$ is given by

$$R(0.95) = 2.4478\sigma_r$$

where $p(r,\theta)$ is given in #4 above.

In selecting the months of data for processing to obtain fix accuracy, winter months were restricted to December/January/February and summer months to June/July/August. For some of the monitoring sites which had limited operation, there were data for only one season. The number of months of data selected for each site and season varied from one to seven months, depending on available data.

The output from the computer program consisted of values of R, σ_r, and D, as discussed above, for the two seasons, two times of day, for each LOP combination. These results were then screened to eliminate LOP pairs which included an OMEGA station which was not considered to be providing coverage (i.e. SNR<-20dB or modal interference) in the signal

accessibility analysis presented earlier in Section 6.1 of this report. In addition, the C-D LOP was eliminated from the data for stations located close to the baseline extension. Specifically these sites were Cambridge, MA., Reading, MA., St. Anthony, Nfld. and Lajes and Vilanova in the Azores.

The resulting tables of R, σ_r, and D are given in Appendix D and recommended LOP combinations are given by geographic area in Section 9 of this report, Interpretation of Results.

6.2.2 Integrated OMEGA/Satellite Fix Accuracy

All usable integrated OMEGA/Satellite data were processed on the Coast Guard's Data General Eclipse S-200 minicomputer using GFE programs. Primarily these integrated data were processed to determine fix accuracy statistics. The computer program allows for many options and/or restrictions as indicated in the Fix Data Summary example in Figure 6-11. For this processing, Longitude was usually segmented in 15° steps while Latitude was not restricted. The times selected were for a five hour period around local midday and midnight. All LOP combinations using OMEGA stations A, B, C, D, E, F were accepted for the daytime data. For nighttime, data stations B and E were eliminated due to the probability of modal interference in the test region. A minimum SNR index of 11, which corresponds to an SNR of -20dB in a 100 Hz bandwidth, was used and the maximum error was limited to 10 nautical miles to eliminate large transient errors. As a result of including all LOP combinations for fix error computation, many poor geometry combinations were included and therefore the error statistics are large.

Summaries of the results of this processing are given in Tables 6-2, 3, 4 for the ANCHORAGE, GALLOWAY and AFRICAN NEPTUNE, respectively.

In processing these data, a listing is available which gives the difference in nautical miles between the satellite system and the OMEGA system for each position fix, for every available LOP combination. This

```
                         OMEGA FIX DATA SUMMARY
                 (DISTANCE/FIX ERROR IN NAUTICAL MILES)

DATE:  27  7 1978 TO  31  7 1978
TIME: 1500  TO 2000
LAT:NOT RESTRICTED
LON: W 7500.00  TO W 9000.00
FREQ: 10.2
STATIONS USED:

A
B
C
D
F

TRANSITION PATHS INCLUDED
SAMPLE SIZE:        70
RANGE:        0. TO 99999.
SNR:  11.0 TO   99.0
SWC: -720.0 TO  720.0
ERRMIN      .00 ERRMAX  10.00

ERROR ABOUT: SATELLITE FIXES (XCOMP=0.0,YCOMP=0.0)
RADIAL ERROR AVE:      2.06 RADIAL ERROR STANDARD DEVIATION:     1.60

     CEP                ERROR
      50                 1.31
      95                 5.28

ERROR ABOUT: XMEAN,YMEAN (XCOMP=     2.57,YCOMP=     -.63)
RADIAL ERROR AVE:      3.45 RADIAL ERROR STANDARD DEVIATION:    1.50
SQRT(SIGMAX**2+SIGMAY**2):      1.76
     CEP                ERROR
      50                 3.36
      95                 6.01
```

Figure 6-8 Example of Integrated OMEGA/Satellite Fix Data Summary

difference between the two systems corresponds to the total fix error (D) introduced in the preceding section (6.2.1). These data have been extracted and combined with the accuracy results from the ONSOD ground monitor sites. However, it should be pointed out that the satellite measurements have their own inherent inaccuracies of a few tenths of a nautical mile up to one-half of a nautical mile. Therefore the shipboard position errors are not entirely due to OMEGA.

TABLE 6-2

SUMMARY OF INTEGRATED OMEGA/SATELLITE FIX ERROR STATISTICS FOR THE ANCHORAGE

LAT °N	LONG °W	N	ERROR ABOUT SAT. FIX (nm) RADIAL ERROR AVE	ERROR ABOUT SAT. FIX (nm) RADIAL ERROR σ	ERROR ABOUT SAT. FIX (nm) CEP 50%	ERROR ABOUT SAT. FIX (nm) CEP 95%	ERROR ABOUT MEAN (nm) RADIAL ERROR AVE	ERROR ABOUT MEAN (nm) RADIAL ERROR σ	ERROR ABOUT MEAN (nm) RADIAL ERROR RMS	ERROR ABOUT MEAN (nm) CEP 50%	ERROR ABOUT MEAN (nm) CEP 95%
LOCAL DAY			OMEGA STATIONS: A, B, C, D, E, F								
17-38	60-75	60	2.4	1.8	1.6	5.4	2.4	1.6	2.0	2.1	5.0
18-24	75-90	212	2.3	2.0	1.6	7.3	2.2	2.1	2.3	1.6	6.5
18-24	75-90	142	2.4	2.2	1.6	7.5	2.4	2.3	2.6	1.6	7.0
18-21	75-90	70	2.1	1.6	1.5	5.3	3.5	1.5	1.8	3.4	6.0
LOCAL NIGHT			OMEGA STATIONS: A, C, D, F								
17-35	60-75	23	5.4	2.0	4.6	8.7	4.9	2.4	4.3	4.5	8.6
18-22	75-90	17	5.1	2.0	5.0	7.2	2.6	2.2	2.6	1.8	5.9

SHIP: ANCHORAGE DATES: JULY 1978

TABLE 6-3

SUMMARY OF INTEGRATED OMEGA/SATELLITE FIX ERROR STATISTICS FOR THE GALLOWAY

LAT °N	LONG °W	N	ERROR ABOUT SAT. FIX (nm): RADIAL ERROR AVE	ERROR ABOUT SAT. FIX (nm): RADIAL ERROR σ	ERROR ABOUT SAT. FIX (nm): CEP 50%	ERROR ABOUT SAT. FIX (nm): CEP 95%	ERROR ABOUT MEAN (nm): RADIAL ERROR AVE	ERROR ABOUT MEAN (nm): RADIAL ERROR σ	ERROR ABOUT MEAN (nm): RADIAL ERROR RMS	ERROR ABOUT MEAN (nm): CEP 50%	ERROR ABOUT MEAN (nm): CEP 95%
LOCAL DAY			OMEGA STATIONS: A, B, C, D, E, F								
40-41	60-75	65	5.8	1.9	3.3	7.4	2.6	2.3	2.2	1.2	7.0
43	45-60	14	5.7	2.2	5.4	8.5	4.2	2.3	2.8	3.0	7.8
42-43	30-45	30	3.8	2.3	3.5	7.1	4.1	2.2	2.8	3.6	7.8
45-46	15-30	75	3.1	2.1	2.5	7.5	3.1	2.1	2.5	2.4	6.8
41	15-30	14	4.7	2.8	4.1	8.9	4.9	3.1	2.6	3.8	9.8
48	00-15	26	1.7	1.3	1.3	2.6	2.2	1.6	1.1	2.0	3.0
LOCAL NIGHT			OMEGA STATIONS:		A, C, D, F						
40°	60-75	12	5.7	2.1	5.4	7.9	5.5	2.8	3.6	4.9	8.7
42-43	45-60	4	3.6	0.2	3.5	3.7	0.2	0.1	0.2	0.2	0.3
42-45	30-45	16	5.8	0.6	5.6	6.7	1.6	1.3	0.6	0.9	3.9
47	15-30	10	5.3	0.9	4.7	6.2	1.8	1.6	0.8	1.4	1.9
40	15-30	4	5.4	2.9	3.2	7.9	5.6	2.7	3.5	3.9	7.4
49-50	00-15	4	6.3	2.0	6.2	7.5	4.6	2.0	5.0	3.8	4.6

SHIP: GALLOWAY DATES: APRIL 1978

TABLE 6-4

SUMMARY OF INTEGRATED OMEGA/SATELLITE FIX ERROR STATISTICS FOR THE AFRICAN NEPT[illegible]

LAT °N	LONG °W	N	ERROR ABOUT SAT. FIX (nm)				ERROR ABOUT MEAN (nm)				
			RADIAL ERROR		CEP		RADIAL ERROR			CEP	
			AVE	σ	50%	95%	AVE	σ	RMS	50%	95%
LOCAL DAY			OMEGA STATIONS: A, B, C, D, E, F								
30-31	75-90	166	3.1	2.3	2.4	7.3	3.5	2.2	3.2	2.9	7.2
25-27	45-60	52	2.3	1.7	1.7	5.7	2.3	1.6	2.4	1.7	6.1
4-10	00-15	33	1.8	1.0	1.4	2.6	1.6	1.0	0.8	1.1	2.5
LOCAL NIGHT			OMEGA STATIONS: A, C, D, F								
28	60-75	11	3.9	1.1	3.5	5.3	3.9	1.4	3.0	3.6	4.7
26	45-60	5	4.8	0.1	4.8	4.8	0.1	0.[illegible]	0.1	0.1	0.1

SHIP: AFRICAN NEPTUNE DATES: OCT., NOV., DEC. 1978

6.3 PHASE BIAS ERROR

The phase error is determined as follows:

Phase Error = Observed Phase - Predicted Phase

where

Predicted Phase = Norminal Phase - PPC.

A study of the ONSOD ground monitor site data indicates that there are some bias errors evident in certain of the phase data. The data base for this study was the unflagged local noon and midnight (five-hour average) 10.2 kHz phase data used for the accuracy calculations.

Table 6-5 lists the apparent bias errors being observed for winter/summer, day/night. The values are an average of the bias errors over the months of observation. In many cases there are only two or three months of observation, which may be too small a sample to warrant considering the improvement of the PPCs. However, there are some instances where bias errors have been observed consistently for four months or more during winter or summer months. These are listed separately in Table 6-6 for Belem, Brazil; Farnborough, U.K.; Hestmona, Norway; La Moure, North Dakota; Nea Makri, Greece; and Sabana Seca, Puerto Rico. In the case of Belem, Brazil, the bias error may be due to a geodetic problem since it is based on a local datum. The cause of consistent bias errors at other monitor sites is not evident and improvement of the PPCs should be considered.

Table 6-5

Phase Bias Errors

SITE	LOP	Δφ - LOP PHASE BIASES (CECS) WINTER				SUMMER			
		N	DAY	N	NIGHT	N	DAY	N	NIGHT
Belem, Brazil	A-C	5	+38			6	+23		
	C-D	6	-31			6	-20		
Bermuda, U.K.	A-C			2	+27				
	A-D			2	+16				
	A-F			2	-34				
	B-C	2	-24	2	-29				
	B-D	2	+16	2	+28				
	D-F	2	-36	2	-25				
Eglin AFB, FLA.	A-C			2	-20				
	A-D	2	-29						
	C-D	2	-13						
Farnborough, U.K.	A-B			3	-19				
	A-D	8	-15			11	-17		
Hestmona, NOR.	B-C					5	-17		
	B-E							4	-40
	B-H					3	-16		
	C-D	5	-13	5	-25				
	C-H	4	-23						
	E-H			2	-28				
Keflavik, Iceland	B-D					2	-18		
	B-F					2	-19		
Lajes, Azores	A-C	2	+14						
	C-F	2	-16						
La Moure, N.D.	A-C	5	+27			3	+14	3	+12
	A-H					2	+14		
	C-H	6	-28						
Nea Makri, GR.	A-B			4	-20				
	A-E	3	-13						
	B-H							2	+22
Panama, C.Z.	B-D					2	+20		
	C-D					2	-11	2	-16
	C-F					2	-20		
Piarco, Trinidad	A-C					3	+13	3	+15
	B-D			3	-36			3	-31
	C-D	3	-23	3	-16	3	-11	3	-13
Portsmouth, VA	A-C	2	+15						
	D-H	2	-18						

N = Number of Months

Table 6-5

Phase Bias Errors (Cont.)

SITE	LOP	Δϕ - LOP PHASE BIASES (CECS) WINTER				SUMMER			
		N	DAY	N	NIGHT	N	DAY	N	NIGHT
Sabana Seca, P.R.	A-C	6	+34						
	A-D	4	+15						
	A-F			2	-38			2	-42
	C-D	5	-24	5	-17			4	-12
	D-F			3	-32			4	-38
St. Anthony, NEWF	A-C	3	+16						
Vila Nova, Azores	D-F							3	+55
Washington, D.C.	A-B			2	+24			3	+23
	A-D			2	-12				
	C-D	2	-14						
	D-H	2	-27						

N = Number of Months

Table 6-6

Phase Bias Errors Observed for Four or More Months

SITE	LOP	Δφ - LOP PHASE BIASES (CECS) WINTER N	DAY	N	NIGHT	SUMMER N	DAY	N	NIGHT
Belem, Brazil	A-C	5	+38			6	+23		
	C-D	6	-31			6	-20		
Farnborough, U.K.	A-D	8	-15			11	-17		
Hes[illegible]mona, NOR.	B-C					5	-17		
	B-E							4	-40
	C-D	5	-13	5	-25				
	C-H	4	-23						
La Moure, N.D.	A-C	5	+27						
	C-H	6	-28						
Nea Markri, GR.	A-B			4	-20				
Sabana Seca, P.R.	A-C	6	+34						
	A-D	4	+15						
	C-D	5	-24	5	-17			4	-12
	D-F							4	-38

N = Number of Months

6.4 EFFECT OF SUDDEN IONOSPHORIC DISTRUBANCES (SIDS) ON THE OMEGA NAVIGATION SYSTEM

SIDS are produced by solar flares and the frequency of occurrence and intensity are related to the 11 year solar cycle. The effects of a SID on VLF radio signals propagating over long paths are a Sudden Phase Advance or Anomaly (SPA) and sometimes, in the case of very large flares, Polar Cap Absorption (PCA) in the auroral zones. Both SPAs and PCAs can affect VLF position fix accuracy and in addition, PCAs can attenuate the signals propagating through the auroral zone to a non-usuable level.

6.4.1 Sudden Phase Advance

A study[20] of the distributions of SPAs has been made which includes the number distributions of the maximum phase offsets produced by SPAs observed at 10.2 kHz on the Hawaii - New York path from 1966 through 1970 (Figure 6-9). This figure clearly shows that there were fewer SPAs and they were smaller during periods of lower solar activity (1966-1967) than near the solar cycle maximum (1968-1970).

Figure 6-10 shows the disturbance duration distributions observed during SPA events for the same path and years. These plots indicate a peaking effect around 40 minutes with a decrease in frequency with length of disturbance. These data do not indicate any significant relationship between disturbance duration and the sunspot number, which nearly tripled over the time span that was analyzed.

A study[21] of SIDs and their effect on VLF position fixing accuracy was commissioned by National Air Traffic Services in conjunction with the Ministry of Defence in the United Kingdom. The study was intended as a reference work for those concerned with the use of VLF propagation for navigation.

A few of the details of this analysis are included here. The results of this study indicate that for a suitable combination of trans-

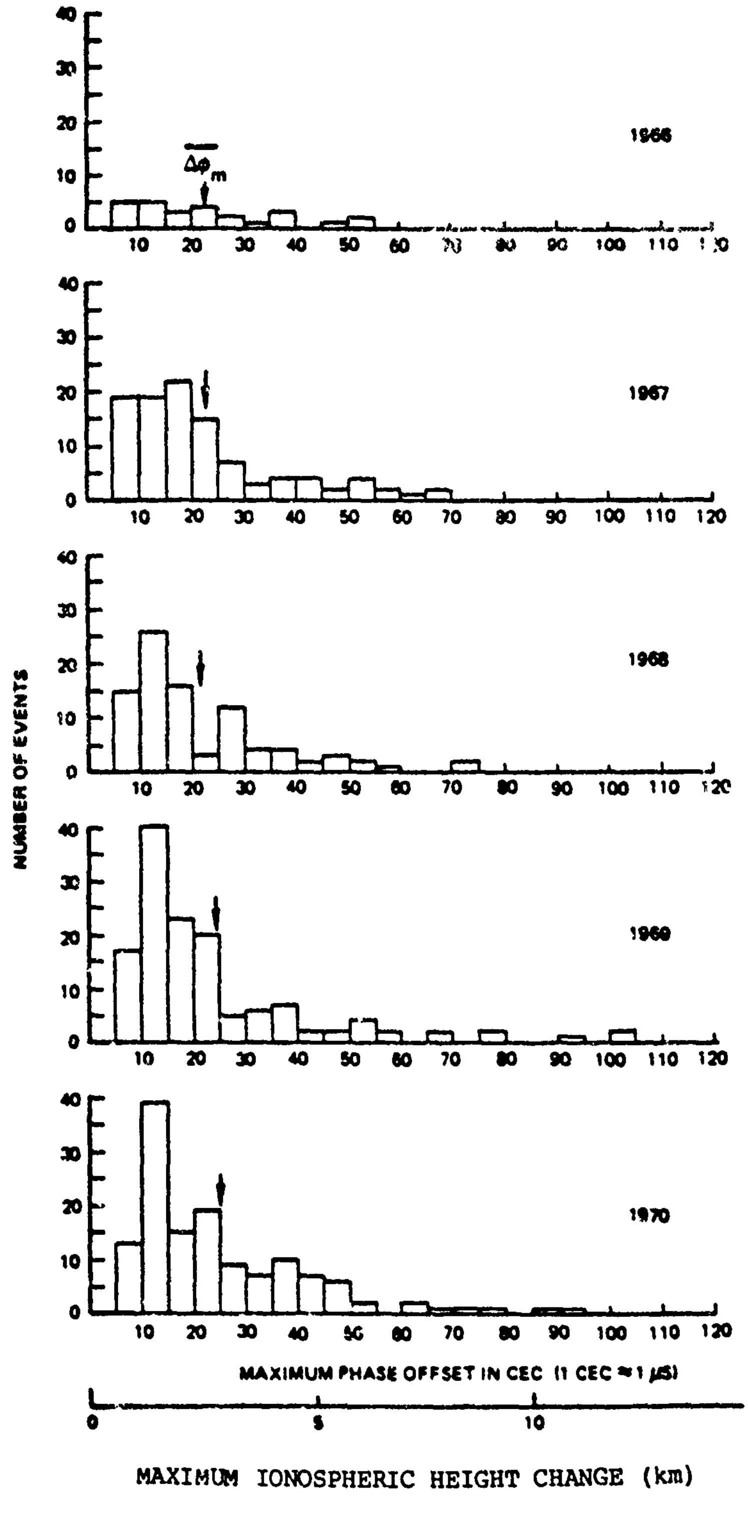


Figure 6-9 Maximum Phase-Offset Distributions Observed during SPA Events on Hawaii to New York Path at 10.2 kHz

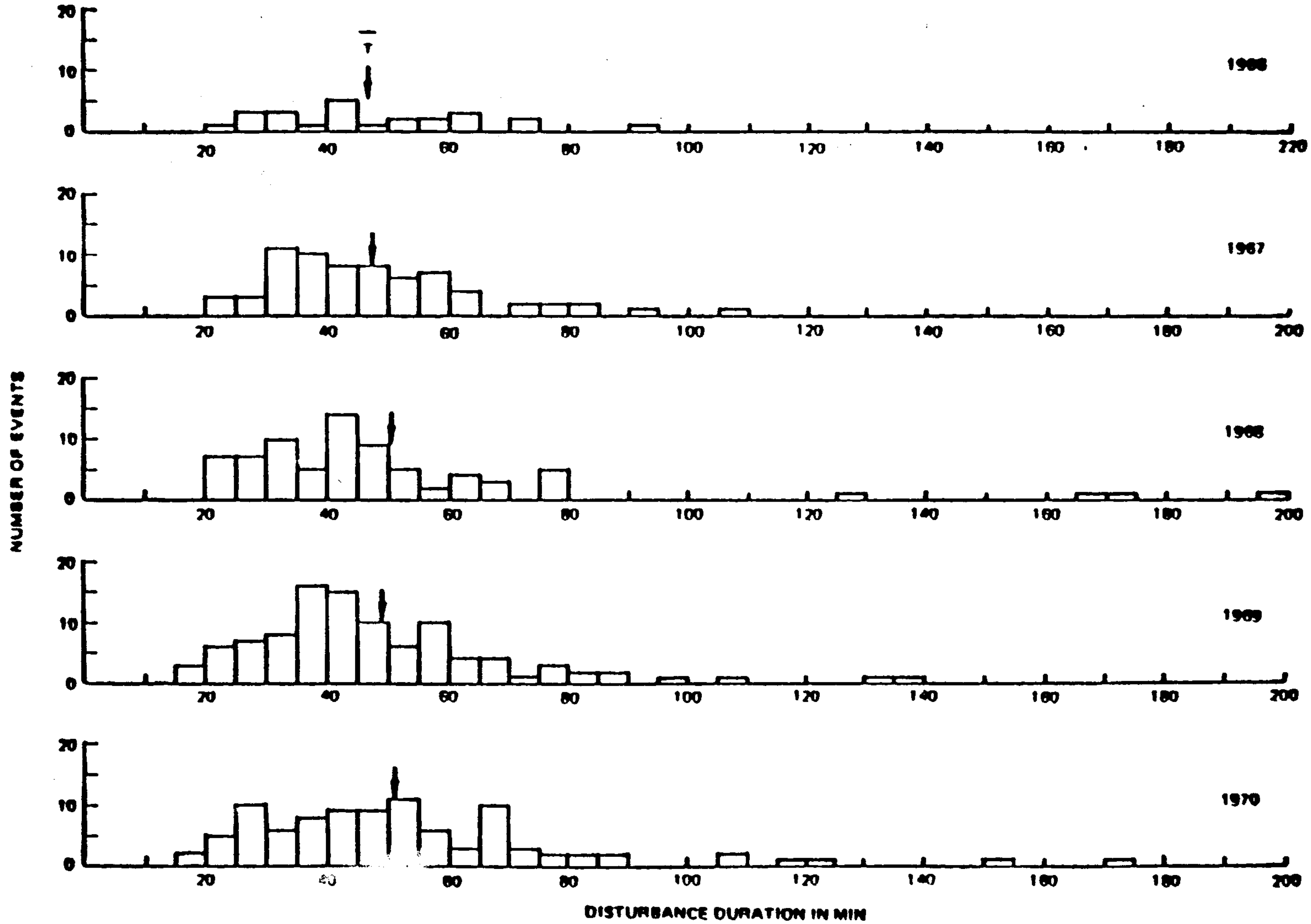


Figure 6-10 Disturbance Duration Distributions Observed During SPA Events on Hawaii to New York Path at 10.2 kHz

mitter stations serving the North Atlantic Organized Track Structure area, SIDs are unlikely to cause positional errors of more than 15 nautical miles.

The phase recordings used in this study came from two main sources:

a. Phase recordings of the Trinidad Omega transmitting station received at RAE Farnborough from 1966 through until 1971. The data were mainly at 10.2 kHz but also included some at 11.3 kHz and 13.6 kHz.

b. Phase recordings of the Trinidad Omega transmitting station received at RGO Hertmonceux from November 1969 to June 1973. These data were at 12 kHz.

These recordings together covered a substantial part of the 11 year Solar Cycle. In particular they covered the period of maximum solar activity when the ionospheric disturbances can be expected to be most frequent and of maximum intensity.

It was unfortunate that no single set of records covered the total period, therefore an attempt was made to use records from both of the above sources despite the different frequencies at which the recordings were made. It was considered that the propagation path was so similar that no correction need be applied for the difference.

Frequency Dependence

The size of the phase shift caused by a SID is dependent on frequency. Fortunately, there was a reasonable amount of overlapping data during 1970 at 10.2 kHz, 11.3 kHz, 12 kHz and 13.6 kHz on the two paths under study. An analysis of these data showed the following relationship.

f_2 (kHz)	Ratio $\left(\frac{10.2\ \text{kHz}}{f_2}\right)$
11.3	1.3
12.0	1.45
13.6	1.7

$$\text{where Ratio} = \frac{\text{Phase Shift on 10.2 kHz}}{\text{Phase Shift on } f_2}$$

Probable Cross Track Errors

All of the SID associated data were converted to 10.2 kHz and normalized to a path length subtending one radian at the center of the earth, under normal illumination. Given a particular transmitting station, date, and time this normalized distribution was converted into an expected distribution at a given receiver. By using three transmitting stations simultaneously, it was possible to deduce a distribution for the errors in hyperbolic position fixing at the receiver.

A receiver position of 52° N. Latitude, 30° W. Longitude was used and several combinations of transmitting stations (3) were used for the study. In each case the months of June and December were included in the analysis. Daily mean examples of the results using Norway, Trinidad and North Dakota are given in Figure 6-11. In each case, the vertical axis is the $\log_{10}$ probability of the cross track error falling in a given range and the horizontal axis is the cross track error in nautical miles. The track in these runs was in the East - West direction, so that the negative cross track error means that the aircraft true position is north of the indicated position.

The daily mean distributions for this combination of transmitting stations indicates a cross track error between -5 nm and +6 nm for June (Figure 6-11a) and between -8nm and 0nm for December (Figure 6-11b). The

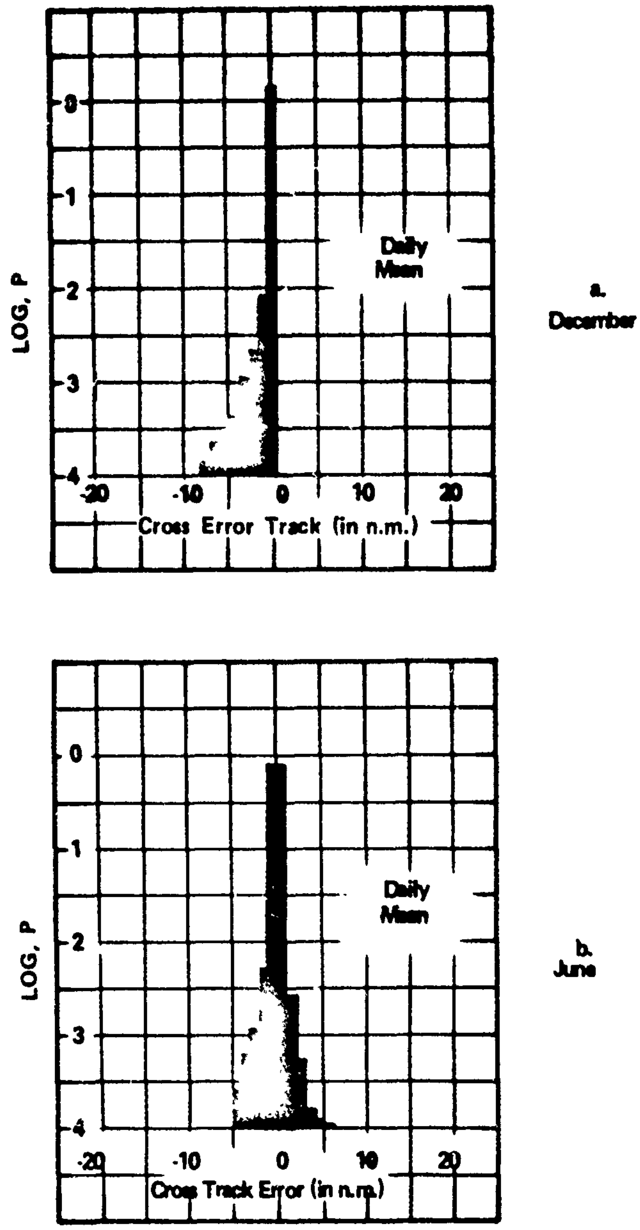


Figure 6-11 Histograms of Cross Track Errors Receiver Position N52° W30°. Track=90°. Transmitters N. Dakota, Norway, Trinidad.

individual hourly data (not shown here) showed that the worst errors occur at about 1300 GMT in December when there is a long sunlit path to Trinidad. Also large errors can occur at 2300 GMT in June when the Norway path can be in sunlight due to the high latitude of this path.

Another analysis task in this study was to derive the variation of cross track errors with different receiver locations using the same combination of transmitting stations. The five receiver locations are shown in Figure 6-12. These are located at the extreme corners of the Oceanic Control Area and a point near the middle. The transmitting stations used were Norway, North Dakota and Liberia which would be considered to provide optimum coverage for this area.

The expected cross track errors observed at these five locations are shown in Figure 6-13a for June and in Figure 6-13b for December. Again the vertical axis represents the $\log_{10}$ of the probability and the horizontal axis represents the cross track error in nautical miles. In both the summer and winter cases the northern most points give the larger errors. This is because these have a longer path to Liberia which has a higher illumination than the other paths. In the June case only, the "Midnight Sun" causes some disturbances at night, which are much larger at the receiver positions which are furthest west (furthest from Norway).

At no time was a cross track error observed that was greater in magnitude than 13 nautical miles. However, if a less optimum triad of transmitting stations had to be used, the error would likely be larger.

Spatial Distribution of Errors with Time

Not only the cross track errors are of interest to those concerned in defining airways and clearances. Also of interest is the direction of the error at any time. As receiver A (Figure 6-12) appeared to give the most dramatic errors in the previous section it was chosen to demonstrate the variation of the total expected error with time. These results are shown in Figure 6-14.

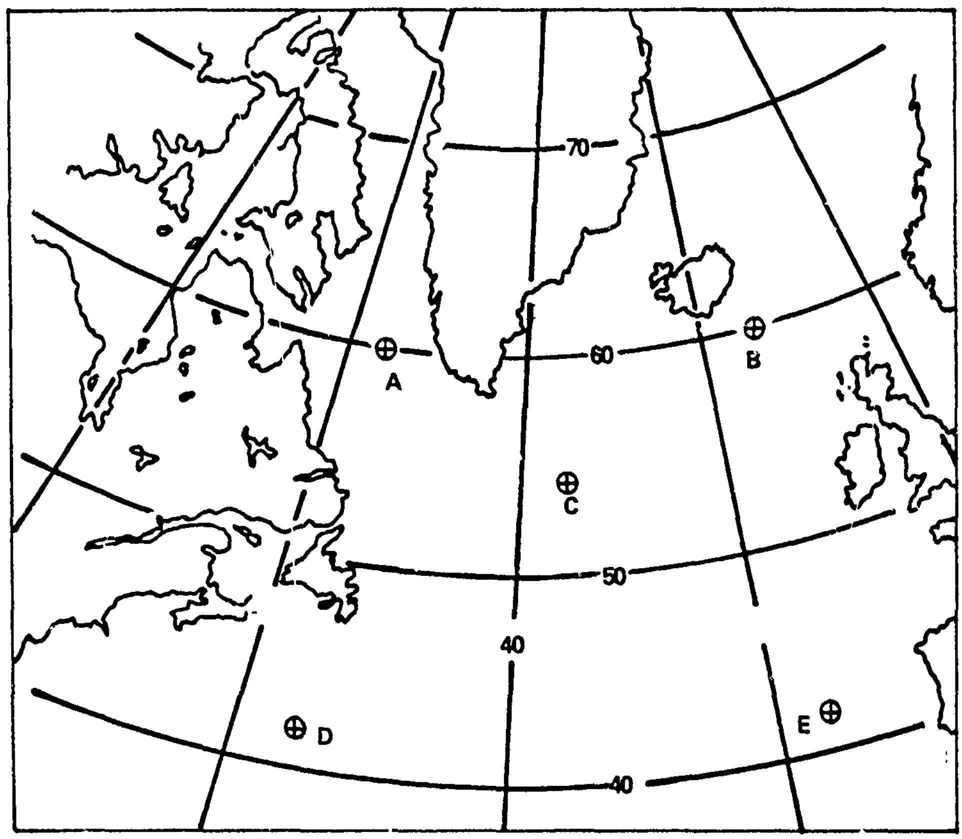


Figure 6-12 The Oceanic Control Area Showing the Five Selected Receiver Locations.

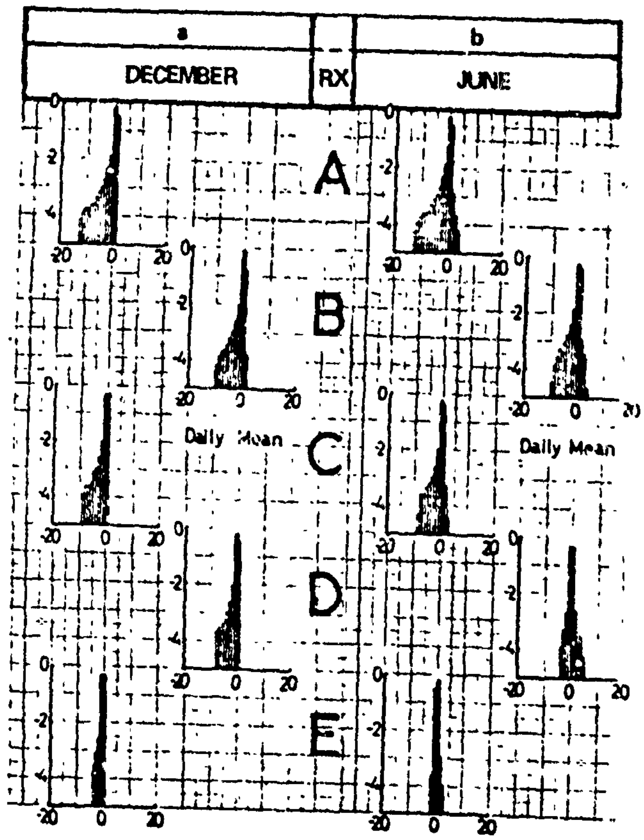


Figure 6-13 Histograms of Cross Track Errors: Transmitters Norway, Liberia and North Dakota. Track=90°. Receiver Positions (as shown in Figure 6-12)

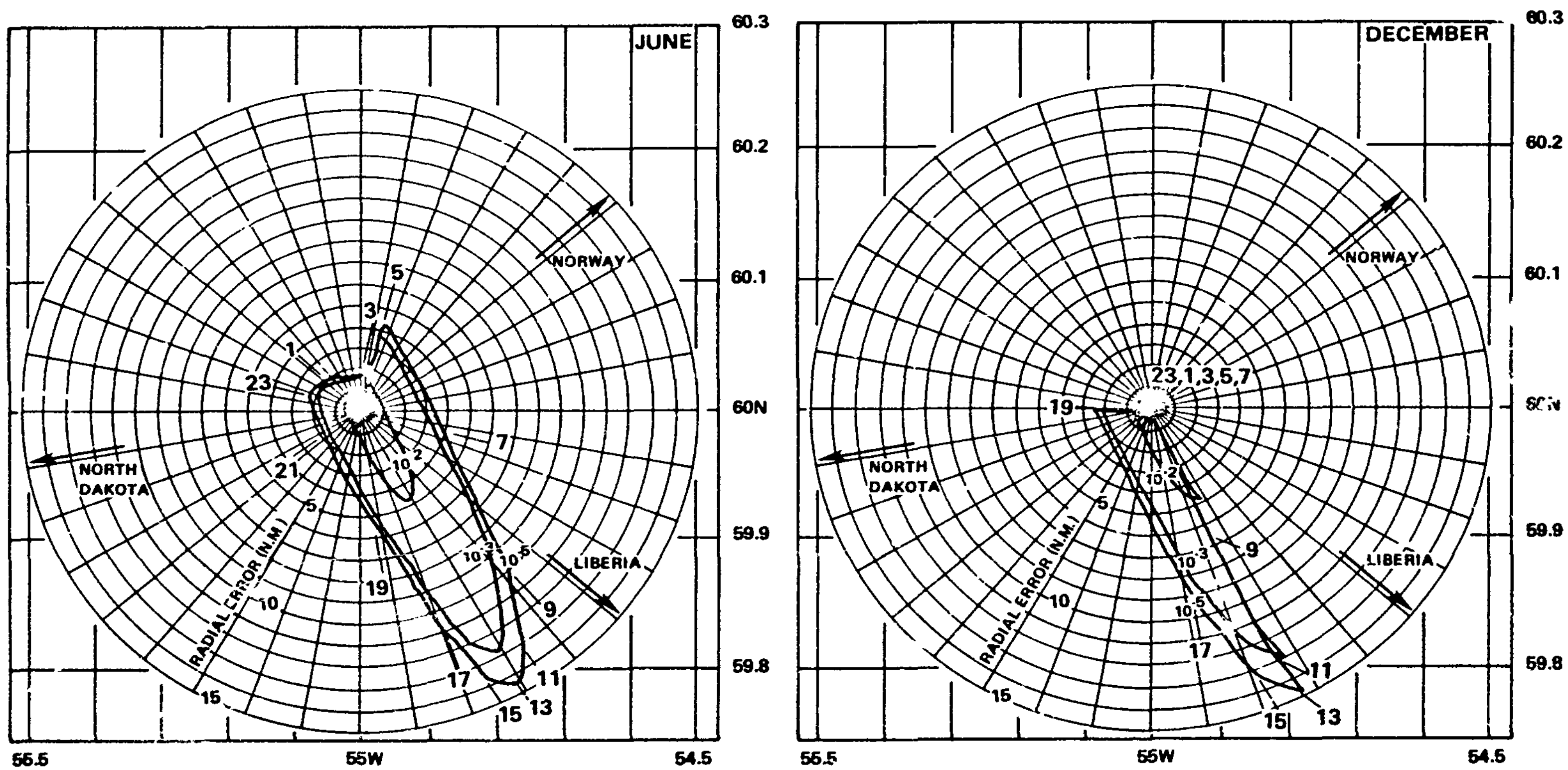


Figure 6-14 Spatial Distribution of Errors

As can be seen in both the runs for June and December, the error is very great in roughly the direction of the Liberian transmitter when that propagation path is illuminated. The error is in roughly the direction of the North Dakota transmitter when only that path is illuminated, and roughly in the direction of the Norway transmitter when only that path is illuminated (June only; Midnight Sun effect).

The diagram shows dramatically the apparent shortening of phase on a sunlit path. The sunrise/sunset data for each path (Table 6-7) is helpful when understanding the shape of the spacial error distribution.

Table 6-7

Sunrise and Sunset Data for Each Propagation Path

Propagation Path	June		December	
	Sunrise	Sunset	Sunrise	Sunset
Liberia	0600	1900	0700	1800
North Dakota	0700	0000	1200	1900
Norway	0000	2200	1100	1300

6.4.2 Polar Cap Absorption

Many of the largest Solar Flares, which produce the SIDs by producing a large hard X ray flux, also produce a stream of charged particles which take from a few hours to about a day to reach the Earth. These particles reach ionospheric altitudes only in the region of the Magnetic Poles where the angle of magnetic dip is steepest. The area effected by these PCAs is the Auroral Zone, between 60° Magnetic Latitude and the Magnetic Pole. Not much effect is observed outside these Zones.

The observed effect of a PCA is to produce a large phase advance which will slowly recover over several days. These effects are normally accompanied by radio "fade outs" so warning systems to report such events would have to use frequencies relatively unaffected by the event.

Data on these events are very scarce, although some work done by NOSC (formerly the Naval Electronics Laboratory Center)[22] using paths from Norway-Wales (Alaska) and New York to Wales suggests that PCAs could dominate those paths for some 5 percent of the observed time during the period of maximum solar activity. It should be stressed, however, that the propagation paths used to obtain those results are both almost entirely within the Auroral Zone and certainly no path in use over the North Atlantic is likely to be affected to the same amount.

7. OPERATIONAL DATA

7.1 DATA SOURCES

OMEGA user aircraft data have been reported by Pan American World Airways, the National Aviation Facilities Experimental Center (NAFEC) the Canadian Armed Forces, the U.S. Naval C-118 Weapons System, the U.S. Air Force 4950th Test Wing and the Soviet Aeroflot Airline. Shipboard data have been reported by a variety of users from several countries including the United Kingdom, Australia, Denmark, Finland, the Netherlands and the United States. In addition, differential OMEGA measurements have been reported, by Redifon Ltd. and the Admiralty Compass Observatory (ACO) of the United Kingdom.

7.1.1 Reported Aircraft OMEGA Data

The following paragraphs summarize the reported OMEGA aircraft data.

Pan American World Airways

OMEGA data are available from three Pan American flights transiting the North Atlantic using dual Canadian Marconi (CMA-740) receiver systems as follows:

New York - Paris	8 May 1979
Paris - Malaga	9 May 1979
Malaga - Bangor	10 May 1979

The data for these flights are in the form of observer notes including a chronological summary. The data also include an SNR index for each frequency (10.2, 11 1/3, 13.6 kHz) and OMEGA Station (A through H) at approximately 30 minute intervals and a calibration curve is pro-

vided. Also included is the position difference between OMEGA measurements and INS measurements.

NAFEC Data[23]

A report is available describing the results of measurements made during five flights in January (6, 7, 20, 21, 23) 1976 across the North Atlantic in a TWA-707. The OMEGA receiver was a Litton ONS-201 and the reference system, an LTN-72 Inertial Navigation System.

Several types of data are included in the report as follows:

a. SNR vs GMT from Stations A through H
b. ONS-201 OMEGA/LTN-72 Inertial - Position Comparison
c. Cross Track and Along Track Error vs GMT
d. Ground speed and distance to waypoint vs GMT

Canadian Armed Forces Data[24]

Data from the Maritime Proving and Evaluation Unit of the Canadian Armed Forces for aircraft flight over Northern Canada on four days, 18, 19, 21, and 26 October 1976 are available. The data are in the form of signal-to-noise ratio indices for all eight OMEGA stations and three frequencies. These data are in tabular form and require the use of a calibration curve which is provided.

Also, data in the form of a signal-to-noise index for five OMEGA transmitting stations (Norway, Trinidad, Hawaii, North Dakota and Japan) for three frequencies (10.2, 13.6 & 11.3 kHz) as measured using a Canadian Marconi receiver are given for the following flights:

Trans-Atlantic Flights

Prince Edward I. to England - 20 May 1975
England to Newfoundland - 28 May 1975

Trans-Canada Flights

15/16 April 1975

18 April 1975

19/20 April 1975

27/28 April 1975

The times and geographic positions are indicated on maps for each set of measurements. A calibration curve is provided to convert the signal-to-noise indices into decibels.

C-118 Aircraft Data[25]

A commercial Litton Aero Production OMEGA Navigation System (ONS), LTN-201, was installed in a C-118B for an operational evaluation by an operational squadron. The purpose of the tests was to evaluate the suitability of a commercial ONS to fulfill the Navy's requirement for long-range overwater navigation and to evaluate position accuracy and reliability of the LTN-201 ONS.

Operative navigation equipment on board the aircraft during the tests consisted of TACAN VOR/DME, sextant and a driftmeter. The majority of flight hours were accumulated during a 1-16 July, 1978 deployment to the Mediterranean. A flight to Puerto Rico and a flight to Mexico in May 1978 were the only other flights made.

Project Speckled Trout
4950th Test Wing (AFSC) - Andrews AFB[26]

Reports are available from the Department of the Air Force, Det. 1, 4950th Test Wing (AFSC), Andrews AFB, Washington, D.C. concerning the operational evaluation of several navigational systems installed on the Speckled Trout aircraft for the period January 1979 through January 1980

Many trans-Atlantic, trans-Pacific and domestic flights were flown. The OMEGA system was evaluated using the fully automatic CMA-719 OMEGA Navigation System. The system provided continuous automatic readouts of aircraft position displayed in various forms, namely latitude/longitude, bearing/distance, track angle/cross track distance etc.

Soviet Aeroflot Data[27]

A Dynell ONS-UP receiver has been used on the IL-62M aircraft of the Aeroflot since October 1977 on flights over the North Atlantic. In the period January - April of 1978, an evaluation of the accuracy of position fixing of the aircraft using the ONS-UP equipment was conducted. This evaluation was performed on board the aircraft while parked at airports in Paris, Lisbon, Frankfurt, Montreal, Rabat, Lima and other airports, as well as during flights over the North Atlantic during approaches of the coastal zone. The references for the accuracy evaluation of OMEGA were coordinates obtained from the measurement of two (2) distances from DME, or azimuth and distance for VOR/DME with distances from the radio beacons of not more than 40 KM.

During the various flights the stability of reception of signals from different "OMEGA" ground stations was also determined.

7.1.2 Reported Shipboard Data

A listing of the ships which reported OMEGA data is given in Table 7-1. These data were reported in various formats and Table 7-1 attempts to summarize the type of information that is available from each ship. In most instances, the OMEGA station pairs being used are indicated. In many cases, OMEGA positions are given simultaneously with a reference system position. However, in some cases, only an OMEGA fix is listed and no comparison can be made. Some of the data includes user's comments and error plots or information derived from the measurements.

TABLE 7-1

SUMMARY OF REPORTED SHIPBOARD DATA

VESSEL	CRUISE	REF. SYSTEM & OMEGA	ERROR PLOTS	ERROR INFOR-MATION
ALABAMA GETTY	U.S. TO GIBRALTAR	X		X
BRITISH RESPECT	CAPETOWN - GENOA		X	
	SPITHEAD - PERSIAN GULF	X	X	
	PERSIAN GULF - EUROPE	X	X	
	EUROPORT - PERSIAN GULF	X	X	
UNKNOWN FINNISH	COAST OF W. AFRICA			X
UNITED OVERSEAS I	16 CRUISES - ENGLAND AFRICA, MEDITERRANEAN, PERSIAN GULF AREA			2 CRUISES
BESKYTTEREN	NORWEGIAN SEA	X		
VAEDDEREN	NORWEGIAN SEA	X		
HMS AURORA	NORWEGIAN SEA	X		
HMS KENT	NORWEGIAN SEA	X		
HMS NORFOLK	PORTSMOUTH - BORDEAUX - GIBRALTAR	X		
HMS BLAKE	BREST - BERMUDA - CARTAGENA - PACIFIC	X		
HMS ARETHUSA	ENGLAND, SWEDEN, BALTIC	X		
HMS POOLSTED	ENGLAND - PORTUGAL			
HMS TROMD	NORTH SEA			
HMS EVERTSEN	GIBRALTAR			
HMAS HOBART	BALTIMORE - GIBRALTAR			X
USS TATTINAL	W. COAST OF ENGLAND			
USS J.F. KENNEDY	U.S. - MEDITERRANEAN	X		
USS WM. PRATT	PUERTO RICO - MARACAIBO - VENEZUELA, LA GUAIRA			
TJERK HIDDES	ENGLAND - PORTUGAL			X
H.NL.M.S. TYDEMAN	Trans-Atlantic	X		X

Also, about a month of OMEGA/Satellite data have been reported by the Netherlands Navy. The data were collected in the North Atlantic region during the November/December time frame. The measurements were made onboard the H.NL.M.S. "TYDEMAN" which was equipped with an automatic data logging system (Oceanlos). Connected to this system were a Magnavox 702A Satellite Navigation system and a Sercel NRNX-4R OMEGA receiver.

At the time of closest approach of a satellite, the system prints: Day/Time/OMEGA receiver readings/propagation corrections and stores the geographical postion which is computed from the readings after application of the propagation corrections. If a satellite-pass results in an acceptable satellite fix, the difference between the stored OMEGA-position and the accepted satellite-position at 'time of fix' is computed.

7.1.3 Differential OMEGA Measurements

Redifon/ACO differential OMEGA measurements at nine monitor sites off the southern coast of England for three station pairs (AB, AD, CD) are given in terms of distance (nm) and bearing. Tables give mean LOP's (day, night, all), standard deviation (day, night, all) and mean error (day, night, all).

7.2 OPERATIONAL DATA EVALUATION

7.2.1 Reported Aircraft Data

The following sections summarize the results of the reported aircraft data.

Pan American World Airways

OMEGA data are available for three Pan American flights (New York-Paris, Paris-Malaga, Malaga-Bangor) made in May 1979. These data consist of OMEGA SNR information and fix differences between a CMC 740 OMEGA Navigation System (ONS) and a Carousel IV inertial navigation system (INS). The maximum and minimum values of SNR (in a 100 Hz bandwidth) for each OMEGA station during each flight are given in Table 7-2.

For the flight from New York to Paris, the typical difference between the ONS and INS was around 3 nm. During the flights from Paris to Malaga and Malaga to Bangor, the difference between the ONS and INS was normally about 2 nm. Actual differences at the landing terminals were 2.1 nm (ONS) and 18 nm (INS) at Orly Airport, 2.4 nm (ONS) and 1.1 nm (INS) at Aeropuerto de Malaga, and 0.5 nm (ONS) and 2.3 nm (INS) at Bangor Airport.

NAFEC Flight Data[23]

A report from the Communications and Guidance Division of NAFEC presents a summary of data recorded during five trans-Atlantic flights in January 1976 using an OMEGA Navigation System, ONS-201, in a TransWorld Airline (TWA) Air-Cargo 707. SNR data are given as a function of time and OMEGA fixes are compared with those measured using a Litton LTN-72 inertial navigation system. During these flights the Norway, Hawaii, North Dakota and Japan stations were operating normally while La Reunion, Argentina and Liberia were testing intermittently.

TABLE 7-2

SUMMARY OF MAXIMUM AND MINIMUM SNRs MEASURED DURING THREE PAN AMERICAN FLIGHTS

	MAX/MIN SNR (dB) IN 100 Hz BANDWIDTH		
STATION	NEW YORK - PARIS (1)	PARIS - MALAGA (2)	MALAGA - BANGOR (3)
A. NORWAY	+12/+5	+8/+6	+12/-2.5
B. LIBERIA	+6.5/-8	+8/+4	+7/-9
C. HAWAII	+2/<-20	<-20	0/<-20
D. N. DAKOTA	+8/+4	+4/<-20	+6.5/-5.5
E. LA REUNION	-14/<-20	-10/<-20	-11.5/<-20
F. ARGENTINA	+4/-11	+1.5/-8	-1/<-20
G. TRINIDAD	+7/+5	+3.5/-18	+8/-7.2
H. JAPAN	<-20	-10.5/<-20	-14.5/<-20

(1) FLIGHT R146, 8 MAY 1979, 0235-0940 Z

(2) FLIGHT TR151, 9 MAY 1979, 0619-0810 Z

(3) FLIGHT R151, 10 MAY 1979, 1125-1911 Z

The SNR data for the normally operating stations can be summarized as follows based on a -20dB threshold:

Norway North Dakota	-Above threshold all flights, day and night
Hawaii	-Above threshold west of ~ 15° Long. during day and ~ 30° Long. during night.
Japan	-Mostly below threshold

Test transmissions from other stations indicated that Liberia provided good coverage across the Atlantic, La Reunion signals were above threshold in the Eastern Atlantic and Argentina was above threshold for three flights and marginal or below threshold for two flights.

Plots of OMEGA position with respect to the INS reference are included. An analysis of these data indicates that 41% of the OMEGA positions were within 2 nm of the reference position and 66% were within 3nm.

Canadian Armed Forces Flight Data [24]

SNR data are available from the Canadian Armed Forces for two trans-Atlantic flights and several flights in Northern Canada. The 10.2 KHz data for the trans-Atlantic flights are summarized in Table 7-3. Included are the maximum and minimum values of SNR for four stations , A, C, D and H.

Additional data have been reported by the Maritime Proving and Evaluation Unit during a northern expedition in October 1976. Most of the data are for the region of 76°-88° N. Latitude and 66°-72° W. Longitude. In this region, the SNR for OMEGA stations A, C, D and H is always greater than the -20dB SNR threshold. Stations B, E and F are always below this threshold. Some data at lower latitudes indicate that station E drops below threshold at ~ 58° N. and stations B and F at ~ 71 ° N.

Also included in this report was the information that they rendezvoused the aircraft with a Royal Navy submarine at 84° 50'N, 69° 12' W. The submarine was using NAV SAT and the difference between the aircraft OMEGA position and the submarine's position was 0.7 nm.

TABLE 7-3

SUMMARY OF MAXIMUM AND MINIMUM SNRs MEASURED

DURING TWO CANADIAN ARMED FORCES TRANS-ATLANTIC FLIGHTS

	MAX/MIN SNR (dB) IN 100 Hz BANDWIDTH	
STATION	P.E.I. - ENGLAND (1)	ENGLAND - NEWFOUNDLAND (2)
A. NORWAY	+12/+8	+12/+9.5
C. HAWAII	-1/<-20	-10.5/<-20
D. N. DAKOTA	+9.5/-4	+7/-2./5
H. JAPAN	-13/<-20	-12/<-20

(1) 20 MAY 1975, 0339-1550 Z

(2) 28 MAY 1975, 1218-2346 Z

C-118 Aircraft Data [25]

OMEGA data were collected onboard a C-118B aircraft in three areas of operation, Conus, Caribbean and Mediterranean in May-July 1978 using a LTN-201 ONS.

The signal quality from all eight stations was recorded at various times during the evaluation. The LTN 201 uses the most distant station for calibration and cannot be used for navigation. It does provide a reference which, together with the hardware and software, make Signal to Noise Ratios (SNRs) as low as -9 dB available for navigation.

In reducing the data, the position data collected were grouped according to the type of reference fix. Visual mark-on-top over surveyed targets is the most accurate way of determining the geographic position of the aircraft. In flight, the aircraft driftmeter was used to determine the geographic position of the aircraft. The altitude of the aircraft and the field of view of the driftmeter were used to ensure that the aircraft was no greater than 1/2 nautical mile from the surveyed point. The fixes using TACAN, VOR, and enroute radar are considered less accurate and were grouped separately. The data taken where no information as to how the fix was obtained were not used even though the accuracy was comparable to the accuracy obtained for the remainder of the evaluation.

The signal quality data were recorded near the waypoints and at the airports. The LTN 201 can display SNR for each station and each of the three frequencies. For statistical purposes, the lowest SNR for the three signals from each station was taken as the value for the station. This gave a pessimistic value for signal quality.

The 55 mark-on-top data points showed an average error of 0.76 nautical miles with a standard deviation of 0.4457. Within this population there were seven data points taken at night. These seven showed the average error to be 0.50 nautical miles. The sample probability distribution is shown in Figure 7-1. The 40 electronic data points showed an average error of 0.77 nautical miles and a standard deviation of 0.3287. The sample probability distribution is shown in Figure 7-2. Figure 7-3 shows the probability distribution for the combined data represented in Figures 7-1 and 7-2. Signal quality data appears in Table 7-4 to portray the percent of samples for a given minimum value of SNR and the minimum number of stations which meet SNR on all three frequencies. All 96 samples were included.

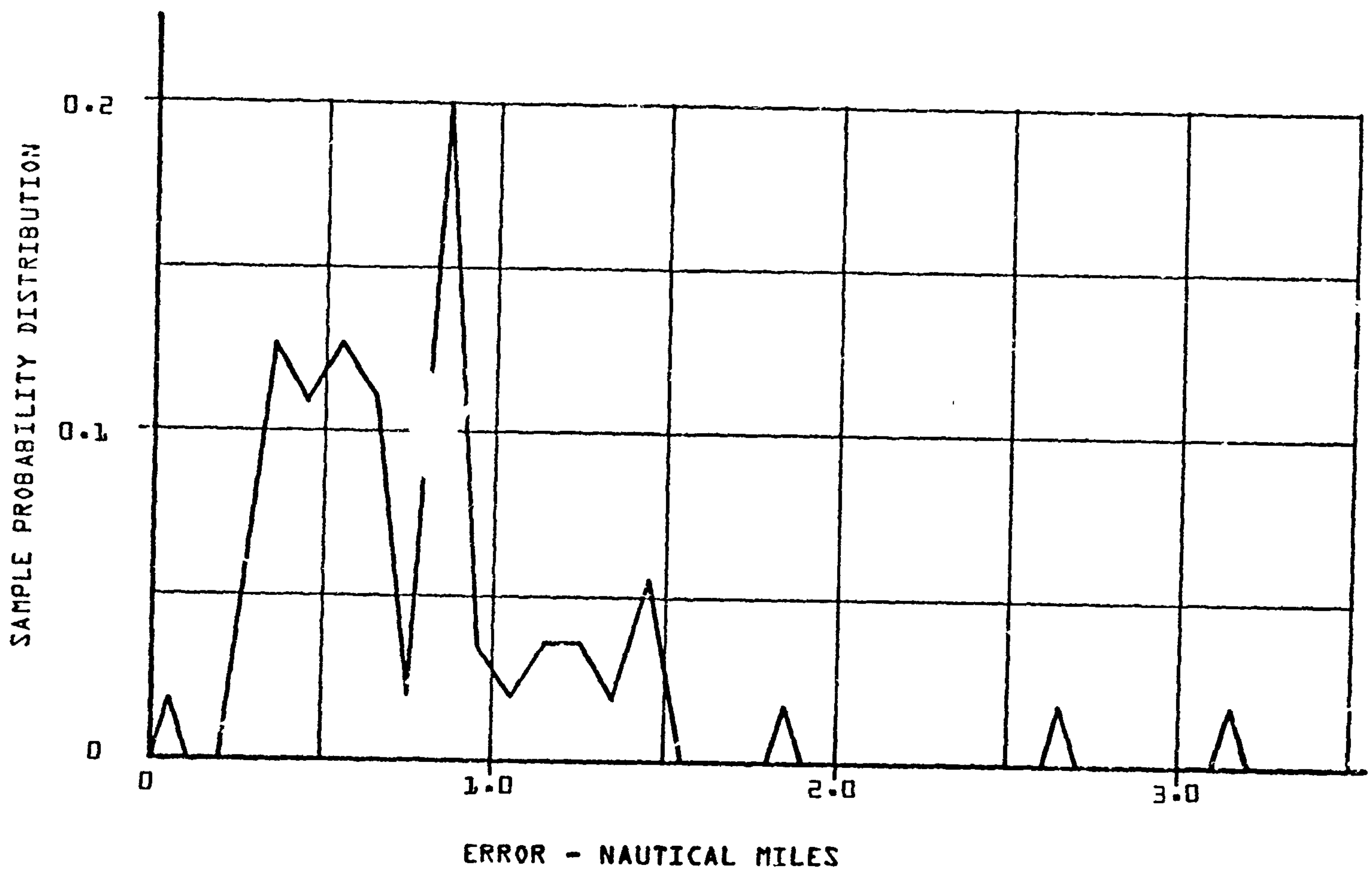


Figure 7-1 Probability Distribution for Mark-On-Top Data Sample

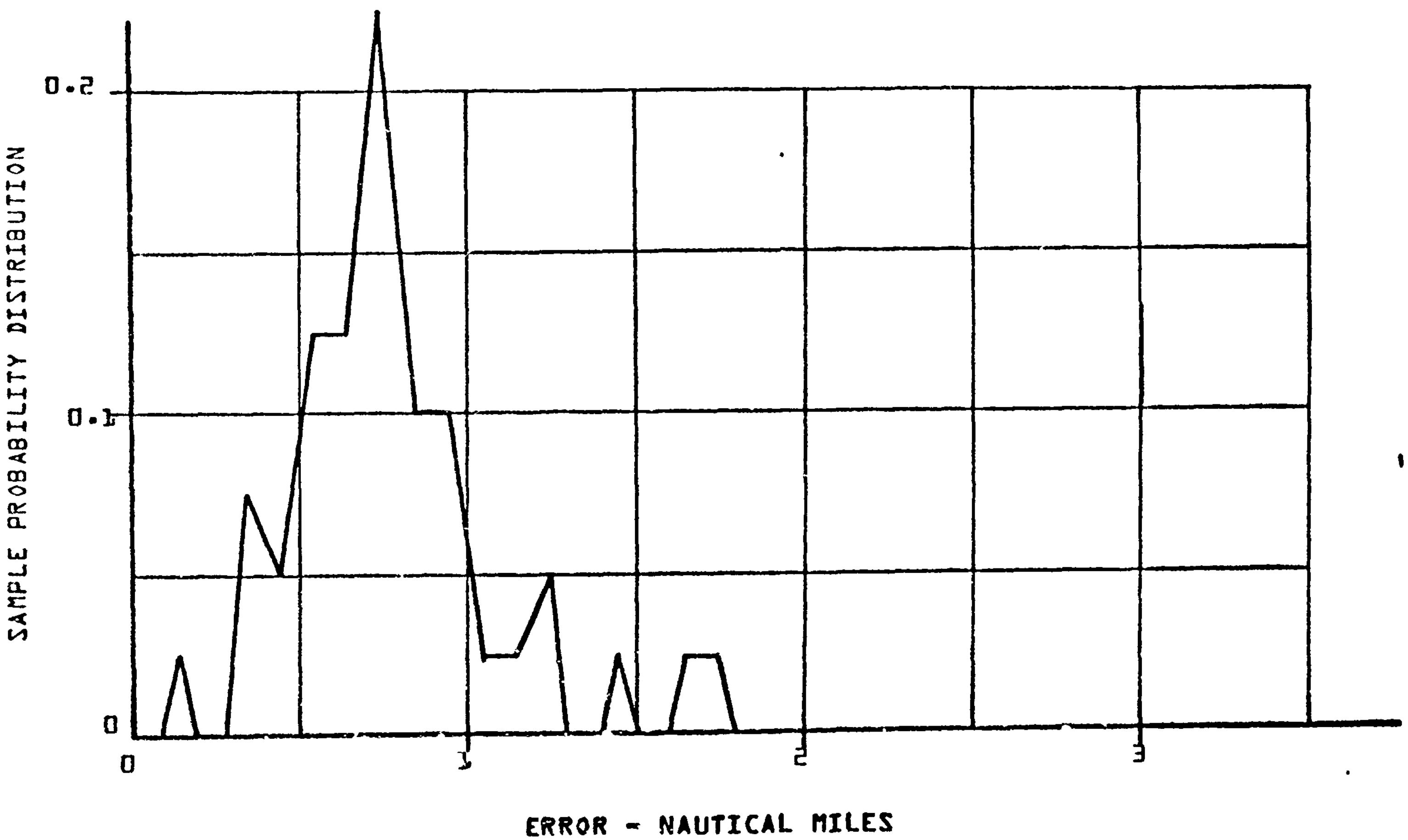


Figure 7-2 Sample Probability Distribution for Data Taken Using Electronic Fixes

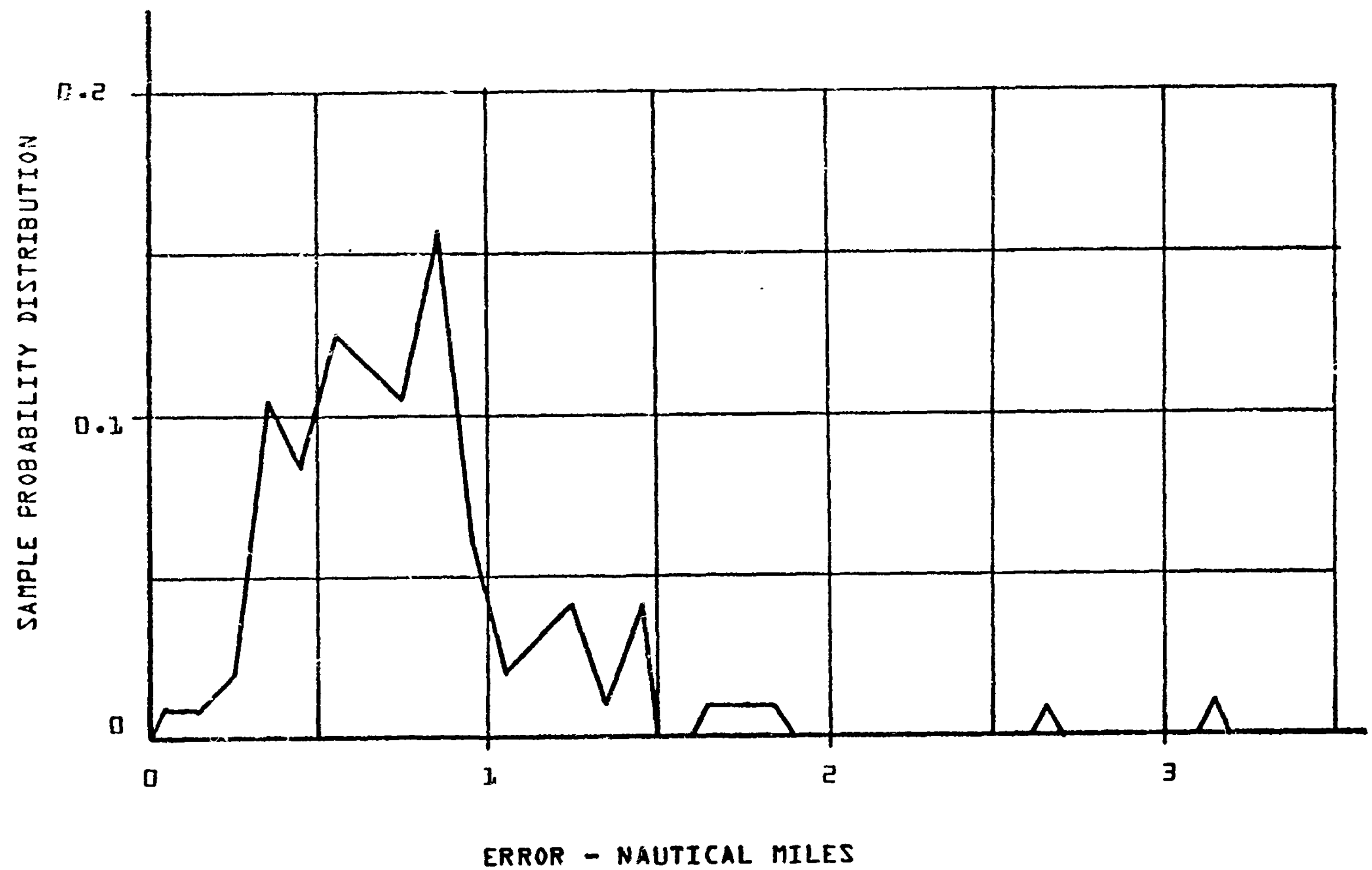


Figure 7-3 Sample Probability Distribution for Data Collected Using Both Methods, Mark-On-Top and Electronic Fixes

TABLE 7-4

Percent of Samples for a Given Signal Quality and Number of Available Stations Useful to Navigation

Minimum SNR dB	Number of Stations					
	2	3	4	5	6	7
+20	89.58	45.82	35.42	0	0	0
+10	92.71	55.21	37.50	1.04	0	0
+5	98.96	89.58	60.41	37.49	1.03	0
+0	100	95.82	88.53	72.91	16.66	2.08
-5	100	98.95	95.83	88.54	73.96	29.17
-9	100	100	100	100	100	87.50

The squadron was required to report ambiguity conditions, relanes, resets and malfunctions. There were no LTN 201 failures. In-flight initializations were accomplished without difficulty by estimating the position of the aircraft. No point estimate could be made as to the reliability of the LTN 201 since no failures or difficulties were encountered.

Project Speckled Trout

4950th Test Wing (AFSC) - Andrews AFB [26]

A summary of the results of the operational evaluation of the OMEGA Navigation System using a CMA-719 ONS onboard the Speckled Trout aircraft is given below in Table 7-5. The results presented include only those OMEGA data derived during flights in the North Atlantic region. These data show that the measured OMEGA radial errors were consistently small, < 3nm, with the exception of two flights on 17 September and 9 December 1979.

Table 7-5 . Project Speckled Trout OMEGA Evaluation Results

Date	Flight Route	Flight Time (Hrs)	OMEGA Radial Error (nm)
13 May 79	Andrews AFB - Bentwaters, U.K	7.2	2.45
15 May 79	Bentwaters, U.K .- Brussels, BE	1.1	0.59
15 May 79	Brussels, BE - Andrews AFB	8.4	2.15
19 May 79	Andrews AFB - Howard AFB, C.Z.	5.3	1.09
20 May 79	Howard AFB,C.Z. - Maiquetia,VEN	2.4	0.60
26 May 79	Maiquetia, VEN - Howard AFB, C.Z.	2.3	1.94
30 May 79	Andrews AFB - Torrejon AB, SP	7.2	1.11
2 Jun 79	Torrejon AB, SP - Andrews AFB	7.9	1.50
28 Jun 79	Andrews AFB - Mildenhall, U.K.	6.6	2.78
29 Jun 79	Mildenhall, U.K. - Brussels, BE	0.95	1.02
29 Jun 79	Brussels, BE - Keflavik, IC	3.3	0.67
30 Jun 79	Keflavik, IC - Andrews AFB	6.3	1.02
17 Sep 79	Andrews AFB - Luxembourg	7.3	3.92
25 Sep 79	Paris - Andrews AFB	9.1	2.14
9 Dec 79	Andrews AFB - Brussels, BE	7.1	6.48
11 Dec 79	Brussels, BE - Andrews AFB	8.2	1.96

Soviet Aeroflot Data [27]

OMEGA data were collected during January-April 1978 using a Dynell ONS-UP receiver on an IL-62M aircraft of the Aeroflot. The data were collected both at airports and during approaches of coastal zones in the North Atlantic. The accuracy of the measured OMEGA geographic coordinates compared with known parking place coordinates is given in Table 7-6 for the airport measurements and compared with DME or DME/VOR coordinates in Table 7-7 for the flight zones. More than 100 measurements were made in each of the indicated zones of Tables 7-6 and 7-7.

During flights over the North Atlantic, the ONS-UP equipment provided stable tracking of OMEGA signals. During flights over the Greenland zone, short-term (up to 35-40 sec) transitions to the dead reckoning mode (DR-mode) were observed.

In the course of the above mentioned period, the crews of aircraft on flights from America to Europe have registered four cases of long-term (up to 3 hours) nonpassage of signals from the OMEGA ground stations. In this case signals from only 1-2 ground stations were received by the equipment.

During flights over land, short-term (15-20 sec) transitions to the DR mode were observed, even though at that time the equipment was receiving signals from 3 to 4 stations.

When flights occurred during cloudy conditions or in zones with lightning activity, the ONS-UP reception indicator operated normally.

Table 7-6 Aeroflot Airport OMEGA Accuracies
Vs Geographic Coordinates

Airport	OMEGA Difference in Kilometers			
	Latitude		Longitude	
	Ave	σ	Ave	σ
Montreal	-3.1	3.2	-2.5	2.2
Chas. de Gaul	0.7	1.4	-5.2	2.6
Lisbon	1.7	2.7	-2.2	3.2
Frankfurt	0.4	2.8	-1.7	4.8
Rabat	0.3	0.7	1.4	3.9
Havana	0.9	4.6	-0.3	2.8

Table 7-7 Aeroflot Flight Zone OMEGA Accuracies
Vs DME or DME/VOR Coordinates

Flight Zones	OMEGA Difference in Kilometers			
	Latitude		Longitude	
	Ave	σ	Ave	σ
Sea Coast of North America	6.8	7.0	7.6	4.4
United Kingdom	2.1	6.9	-0.2	8.6
France	-0.6	4.0	-4.6	3.4
Italy	-5.4	4.9	5.0	7.3
North Africa	6.4	3.6	2.7	2.0
Bermuda Is.	-2.1	8.1	6.3	5.1
Nassau	-3.6	6.5	-1.9	4.7

7.2.2 REPORTED SHIPBOARD DATA

OMEGA shipboard data have been reported in a variety of ways from numerous ships as listed in Table 7-1. The following sections summarize the results of these reported shipboard data. It should be noted that the difference between the OMEGA fix and a reference system is given in many cases. Because no estimate of accuracy of the reference system is included, the differences in position can not be concluded as OMEGA errors but rather a measure of the re ionship between the two systems.

<u>Alabama Getty</u> (28)

A report from the Hemisphere Transportation Corp. of Wilmington, Delaware gave fix measurements using a Redifon NV1 OMEGA Navigator on board the Alabama Getty during a cruise from the United States to Gibraltar during December 1976. A comparison between the OMEGA fixes and those derived from other means, typically dead reckoning or sight in this case, is given in Table 7-8 as a function of date, location, and LOPs. Typically there were 6-10 readings each day. The average daily difference between the OMEGA fix and the reference system fix ranged from 3-8 nm.

<u>United Overseas I</u> (29)

A considerable amount of OMEGA fix data were reported by the United Overseas I of the United Overseas Corporation for the years 1977 to 1979. Only a few of the cruises were in the Northern Atlantic and in most cases, a reference position fix was not reported. However for two cruises from the south of England down the west coast of Africa, some OMEGA accuracies were reported. These OMEGA accuracies averaged 3.1 nm in May 1977 and 2.3 nm in October 1977. In both cases the LOPs used were A-D, A-G, and G-D.

TABLE 7-8 ALABAMA GETTY MEASUREMENTS

VESSEL: Alabama Getty

5636

DATE 1976	APPROXIMATE LOCATION		OMEGA LOPs	REFERENCE SYSTEM	AVERAGE DIFFERENCE (NM)
	LATITUDE	LONGITUDE			
DEC-10	38^{O}-17^{O}N	74^{O}-18^{O}W	AC/BC/BF	D/S/X	5.17
DEC-11	35-40	69-46	AC/BC/BF	D/S	7.47
DEC-12	32-53	62-48	AC/BC/DF	"	8.29
DEC-13	33-02	55-48	AC/BC/DF	"	7.66
DEC-14	33-06	50-35	AC/BC/BF	"	5.04
DEC-14	33-26	46-55	AC/BC/AF	"	7.48
DEC-15	33-16	40-59	AC/AD/AF	"	5.00
DEC-16	33-43	33-55	AC/AD/AF	"	6.90
DEC-16	33-12	33-30	AC/AD/BC	"	4.71
DEC-16	33-08	31-23	AC/AF/BC	"	7.05
DEC-17	33-06	29-05	AC/AF/BC	"	6.94
DEC-17	33-10	26-17	AD/AF/BF	"	3.49
DEC-18	33-06	23-59	AD/AF/BF	"	6.01
DEC-18	33-02	20-36	AB/BD/EF	"	8.27
DEC-18	33-26	18-12	AB/BD/-	"	8.36
DEC-19	33-40	16-48	AB/BD/-	"	6.78
DEC-19	34-28	12-52	AB/BD/DE	"	7.15
DEC-20	35-27	08-15	AB/BD/DE	"	3.45

REF. SYSTEM: S-SIGHT
X-VISUAL, DECCA, RADAR, SATELLITE

Finnish Vessel [30]

A report was received concerning findings by a Finnish vessel operating with OMEGA off the West Coast of Africa. The receiver used was a C. Plath Model 1107, single channel, measuring three LOPs simultaneously. Transmitters employed were Norway, North Dakota and Liberia (Argentina was used when the ship was in the vicinity of the Liberia station).

The receiver was in use 152 days, during which time the recorder tapes showed a total of counted stoppages of 14 days. These stoppages were due to atmospheric disturbances as well as interrupted transmissions. The atmospheric disturbances were most frequent in the "Intertropical" zone off Guinea, where tropical and subtropical masses of air mixed. The longest period of disturbances experienced lasted for 20 hours. Usually the disturbances only lasted for half an hour. A total number of 101 disturbances were recorded. It may be pointed out, that of the whole operative time, 9% of it was lost for position fixing.

Observations used for calculations and computing purposes were taken either in port or by radar in the vicinity of the coastal line. The accuracy of OMEGA measurements made off the West Coast of Africa was 3.5 miles during daytime and 5.5 miles at nighttime.

British Respect [31]

A considerable amount of OMEGA fix data were reported by the British Respect of the BP Tanker Company Ltd, London, England. Most of these data were for areas outside of the Northern Atlantic region and have not been evaluated. However there were data for one area of interest, an area along the west coast of Spain and Africa. The average daily difference in fix between OMEGA and a reference system, Decca, Dead Reckoning or radar, are given in Table 7-9 for this area. Typically these average position differences are 2-5 miles.

TABLE 7-9 BRITISH RESPECT MEASUREMENTS

VESSEL: British Respect

5636

DATE	APPROXIMATE LOCATION		OMEGA LOPs	REFERENCE SYSTEM	AVERAGE DIFFERENCE (NM)
	LATITUDE	LONGITUDE			
OCTOBER 11, 1977	45 – 11 N	08 – 44 W	A/B B/D D/E	X	2.55
OCTOBER 12,	40 – 28	11 – 20	A/B B/D D/E	X	2.00
OCTOBER 13	36 – 02	13 – 05	A/B B/D D/E	D	3.70
OCTOBER 14	31 – 29	14 – 37	A/B B/D D/E	D	7.40
OCTOBER 15	27 – 07	16 – 13	A/B B/D A/F	R/D	2.95
OCTOBER 16	21 – 34	17 – 56	A/B B/D A/F	D	5.24
OCTOBER 17	16 – 39	18 – 05	A/B B/D A/F	D	5.04
OCTOBER 18	11 – 37	18 – 00	A/D D/F A/F	D	2.58
OCTOBER 19	08 – 54	15 – 09	A/D D/F A/F	D	2.33
OCTOBER 20	05 – 20	12 – 46	A/D D/F A/F	D	4.99
OCTOBER 21	01 – 38	09 – 37	A/D D/F A/F	D	5.78
OCTOBER 22	02 – 06	06 – 53	B/E E/F B/F	D	2.12

REF. SYSTEM: X – DECCA
R – RADAR
D – DEAD RECKONING

Danish Navy (32)

OMEGA reports for the last three months of 1977 have been received from two Danish Naval ships, the VAEDDEREN and the BESKYTTEREN. The reference systems used were R (assumed radar), D (assumed Decca), L (assumed Loran) and B (defined as Bestik). Reduction of some of these data shows an OMEGA accuracy of 1.5 to 5.4 nm for the VAEDDEREN on a cruise from Greenland to the North Sea in October 1977 and 1.4 to 4.5 nm for the BESKYTTEREN during December 1977 while operating in the North Sea. LOPs A-B, A-D and B-D were used for both cruises.

British Navy Ships

OMEGA data have been reported by eight British Naval ships as follows:

HMS Kent
HMS Norfolk
HMS Blake
HMS Arethusa
HMS Aurora
HMS Poolsted
HMS Tromd
HMS Evertsen

The reference system most commonly used was Decca although in a few cases it was described as alongside. These data have been evaluated and the average difference between the OMEGA fixes and the reference system used can be summarized as follows:

Area of Cruise	Ave. OMEGA Fix Diff. nm	LOPs
Atlantic Crossing	3.4	A-B, A-D, B-D/B-F; A-F, A-C, B-F
Gibraltar Bay	2.2	A-B, B-D, A-D
North Sea	4.7	A-B, A-D, B-D/D-F; B-H, B-C
English Coast	3.4	A-B, A-D, B-D

Australian Naval Ship (33)

The Australian Naval Ship, the HMAS Hobart, has reported OMEGA accuracies measured during a cruise from Baltimore to Gibraltar, 10-20 July 1976. Two OMEGA receivers were used, a Dynell 300 and a Navidyne ESZ 1001A. These measured accuracies are given in Table 7-10. Over a 10 day period, the average difference in position between OMEGA and the reference system was 3.6 nm.

Apparently the reference system that was used was celestial navigation. They report that astronomical conditions were very poor due to fog and that the assessed OMEGA accuracy may have been better than that given in Table 7-10 due to the infrequency of observed positions. Also, they indicate that the OMEGA system was generally stable with few LOPs slipping.

U.S. Navy Ships

OMEGA fix data have been reported by three U.S. Navy ships, the USS TATINALL, the USS JOHN F. KENNEDY and the USS WM. V. PRATT. The USS TATINALL data are for 13 days in June/July 1978 operating along the west coast of England. LOPs AD, AB and BD were used during the majority of the time. These data did not include any reference system position and thus the OMEGA fix accuracies could not be evaluated.

About 95% of the USS WM. V. PRATT data are for the Southern Atlantic region. Seven days of OMEGA data collected in the area south of Puerto Rico and along the Northeast Coast of South America were included. Various combinations of LOPs were used including AG, GD, AD; DF, CD, CF; DF, BD, BC; GD, GF, DF; and DF, AF, BF.

The data from the USS JOHN F. KENNEDY are for a cruise from the east coast of the United States to the Mediterranean in June/July 1978. In addition to OMEGA fixes, many satellite positions are given. However, the OMEGA and satellite fixes are not simultaneous and therefore the data are not suitable for evaluating OMEGA accuracies.

TABLE 7-10

OMEGA FIX ACCURACY ONBOARD HMAS HOBART ON
CRUISE BETWEEN BALTIMORE AND GILBRALTAR

DATE	NO. OF FIXES	AVERAGE ACCURACY	LOP'S USED	REMARKS
11 JUL 76	13	5 NM	AC, AF, DC, BF, DG	CB and BF adjusted for lane slip
12 JUL 76	15	4 NM	AC, AD, AF, BC, BF	BC adjusted for lane slip
13 JUL 76	13	4 NM	AC, AD, AF, BC, BF	BC adjusted for lane slip
14 JUL 76	13	4 NM	AC, AD, AF, BC, BF	
15 JUL 76	11	2 NM	AC, AD, AF, BC, BF	
16 JUL 76	14	5 NM	AC, AD, AF, BC, BF	BC and AC adjusted for lan slip
17 JUL 76	9	5 NM	AC, AD, AF, BC, BF	
18 JUL76	13	3 NM	AC, AD, AG, CG, DG	
19 JUL 76	14	3 NM	AC, AD, AG, CG, DG	
20 JUL 76	3	5 NM	AC, AD, AG, CG, DG	
		Ave. 3.6 NM		

TJERK HIDDES

Three days of data collected between England and Spain were reported by the Netherlands Ship, TJERK HIDDES. The reference system for these data was the Decca navigation system. OMEGA LOPs used were AD/BD and AB/BD. The average difference between the OMEGA and Decca fixes was 3 nm.

The Netherlands Navy OMEGA/Satellite Data

Most of the Netherlands Navy OMEGA/Satellite data collected on board the H.NL.M.S. TYDEMAN are summarized in Table 7-11. Listed are the latitude and longitude, and the bearing and distance (in nautical miles) between the Satellite fix and the OMEGA fix. The maximum measured distance between the two systems for these data is 4.7nm and the average is 2.0 nm.

Table 7-11

Summary of the Netherlands OMEGA/Satellite Data

N. Latitude	W. Longitude	Satellite to OMEGA Bearing (Deg)	Satellite to OMEGA Distance (nm)
25° 45.09'	16° 56.30'	332.8	3.1
24° 10.95'	17° 22.67'	278.3	1.7
24° 7.74'	17° 24.65'	270.5	2.8
24° 7.00'	17° 24.69'	263.3	4.7
21° 31.98'	18° 4.39'	271.6	2.4
21° 33.57'	18° 7.07'	325.3	1.2
21° 26.49'	18° 13.87'	307.8	1.4
21° 32.18'	18° 5.52'	254.4	2.1
21° 32.63'	18° 4.56'	245.0	2.5
21° 25.76'	18° 15.33'	244.4	1.7
19° 56.26'	28° 52.84'	261.9	0.9
19° 56.76'	28° 53.22'	247.0	2.4
19° 57.40'	28° 55.40'	268.6	1.0
19° 55.83'	30° 45.10'	303.4	4.4
20° 1.59'	32° 6.05'	252.3	1.7
20° 0.92'	32° 6.25'	238.9	1.2
29° 15.49'	33° 33.92'	214.1	2.3
29° 44.17'	33° 7.24'	202.1	0.6
29° 59.33'	32° 52.45'	222.9	1.9
41° 26.68'	24° 5.10'	245.9	2.8
42° 3.93'	23° 51.56'	288.5	1.2
42° 7.29'	23° 50.06'	278.5	1.9
42° 25.20'	23° 44.17'	286.7	1.8
42° 28.68'	23° 42.91'	284.6	2.0
42° 39.46'	23° 38.57'	287.5	2.6
42° 54.19'	23° 23.23'	283.1	3.1
43° 17.82'	22° 24.82'	247.1	2.4
43° 24.06'	22° 10.53'	247.5	1.9
43° 32.19'	21° 51.27'	207.8	1.4
43° 33.82'	21° 46.95'	202.1	1.7
43° 38.87'	21° 34.00'	168.8	0.9
43° 43.83'	21° 21.74'	172.5	0.9
43° 52.05'	21° 01.40'	215.7	1.6
		AVE	2.0

7.2.3 United Kingdom Differential OMEGA

OMEGA data from 10 monitor sites off the southern coast of England yield position-fix errors using LOPs AB, AD, and BD before and after application of differential correction techniques. These are summarized below in Table 7-12 based on our interpretation of the data. These measurements were provided as the results of tests conducted by Redifon Ltd. for the Admiralty Compass Observatory, Slough, England of the Admiralty Surface Weapons Establishment.

TABLE 7-12

DIFFERENTIAL OMEGA RESULTS

Monitor Location	No. of Obs	Mean Error (nm)	Improvement Factor
Swansea	15	0.45	N/A*
Round Island	39	0.07	21:1
Penzance	118	0.33	4:1
St. Anthony's Head	38	0.55	2.5:1
Falmouth	24	0.31	5.3:1
Eddystone L/H	17	0.53	2.7:1
Plymouth (1)	93	0.68	2:1
Plymouth (2)	22	0.75	11:1
Yarmouth	24	1.45	1.7:1
Salt Mead	15	1.56	1:1

*Not Available

8. USER NAVIGATION REQUIREMENTS

Navigation services are required by both military and civil users. The requirements vary depending upon the activities in which the users are engaged, the locations in which the activities occur, the relation to other craft and physical hazards, and to some extent the type of craft. Because these differences exist, the requirements for navigational services are divided by classes or type of users and the phases of navigation. Table 8-1 from the Federal Radionavigation Plan[5] shows the emphasis placed on existing radionavigation systems in the various phases of navigation.

As is evident from this table, the OMEGA Navigation System is the primary system for oceanic enroute air users and oceanic marine users.

A Minimum Navigational Performance Specification (MNPS) has been developed under the auspices of the International Civil Aviation Organization (ICAO) for the North Atlantic airspace.[34] A comparable maritime international standard for ships operating in oceanic areas apparently does not exist. Therefore, in this report, the maritime oceanic navigation requirements given in the Federal Radionavigation Plan are presented.

8.1 CIVIL AIR OCEANIC NAVIGATION REQUIREMENTS[5, 34]

A Minimum Navigational Performance Specification (MNPS) was implemented on 29 December 1977 in the North Atlantic Region air traffic control (ATC) system. The MNPS developed under the auspices of the International Civil Aviation Organization (ICAO) is intended to be operative in the North Atlantic Region at least through 1987. The MNPS concept is also used in the Central East Pacific between the U.S. Mainland

TABLE 8-1

RADIONAVIGATION SYSTEM APPLICATIONS

SYSTEM	VOR/DME	TACAN	LORAN-A***	OMEGA	LORAN-C	RADIO-BEACON (NDB/RBN)	ILS/MLS	TRANSIT	NAVSTAR GPS
Phase of Navigation									
AIR									
ENROUTE/TERMINAL									
*Remote Area	E	E	—	E	E	S	—	—	E
*Helicopter	E	E	—	E	E	S	—	—	E
Oceanic En route	—	—	—	P	—	—	—	—	E
Domestic En route	P	P	—	S	E	S	—	—	E
Terminal	P	P	—	—	E	S	—	—	E
APPROACH/LANDING									
Non Precision	P	P	—	—	E	S	—	—	E
Precision	—	—	—	—	—	—	P	—	—
MARINE									
Oceanic	—	—	—	P	S	S	—	P	E
Coastal	—	—	—	—	P	S	—	—	E
*Harbor & Harbor Approaches	—	—	—	—	E	—	—	—	E
*Inland Waterways	—	—	—	—	—	—	—	—	—
LAND**									
AVM/AVL	—	—	—	—	E	—	—	—	E
Site Registration	—	—	—	—	E	—	—	S	E
SPACE									E

LEGEND

P — Primary System

S — Secondary/Supplemental System

E — System in Evaluation

*New Requirement

**This area is under assessment

***All US LORAN-A service is being terminated no later than December 31, 1980

and Hawaii. Also, performance specifications for other portions of the world's airspace are being addressed by ICAO's Review of the General Concept of Separation Panel.

The demand for space over the North Atlantic has led to the use of an airspace route configuration known as composite tracks. The composite track route structure approximately doubles the capacity of the airspace over the conventional route system. The composite route structure staggers the flight level by 1000 feet between aircraft operating on adjacent routes while retaining 2000 feet vertical separation between aircraft on the same route. The lateral spacing between aircraft operating at the same level is 120 nm in the North Atlantic.

While the current organized track system for the North Atlantic and Central East Pacific uses composite separation, it is expected that a non-composite 60 nm lateral separation standard will go into effect on the North Atlantic fixed route system in October 1980.* The following system performance (MNPS) is required to achieve this separation:

1. The standard deviation of the lateral track errors shall be less than 6.3 nm, i.e., 12.6 nm (2 sigma).

2. The proportion of the total flight time spent by aircraft 30 nm or more off track shall be less than 5.3×10^{-4}, i.e., less than one hour in about 2,000 flight hours.

3. The proportion of the total flight time spent by aircraft between 50 nm and 70 nm off track shall be less than 1.3×10^{-4}, i.e., less than one hour in about 8,000 flight hours.

Estimates are that a 30 nm composite lateral separation will be required in the future to meet the expected increased traffic, and for fuel economy. A 30 nm separation will require a lateral track error of less than $\pm$ 6.2 nm (2 Sigma)

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*Private Communication with FAA

8.2 CIVIL MARINE OCEANIC NAVIGATION REQUIREMENTS

From the Federal Radionavigation Plan[5], the requirements for safety of navigation in the ocean phase for all ships are given in Table 8-2. These requirements must provide the master with a capability to avoid hazards in the ocean (e.g., small islands, reefs) and to plan correctly the approach to land or restricted waters. For operational purposes, repeatability is necessary to locate and return safely to the vicinity of a maritime distress, as well as for special activities such as hydrography, research, etc. Economic efficiency in safe transit of open ocean areas depends upon the continuous availability of accurate position fixes to enable the vessel to follow the shortest safe route with precision thus, minimizing transit time and permits tighter, more productive scheduling of terminal facilities.

Requirements[5]

For safe general navigation under normal circumstances, the requirements for the accuracy and frequency of fixes on the high seas are not very strict. As a minimum, these requirements include a predictable accuracy of 2-4 nm coupled with a maximum fix interval of two hours or less. Predictable accuracy is the accuracy of positioning with respect to geographical coordinates[7]. These minimum requirements would permit reasonably safe oceanic navigation, provided that the navigator understands and makes allowances for the probable error in navigation, and provided that more accurate navigational service is available as land is approached. While these minimum requirements would permit all vessels to navigate with relative safety on the high seas, more desirable requirements would provide a predictable accuracy of 1-2 nm and a fix interval of 15 minutes or less.

Larger recreational craft and smaller commercial fishing vessels which sail beyond the range of coastal navigation systems require, for a reasonable level of safety, some means of establishing their position

TABLE 8-2

CURRENT MARITIME USER REQUIREMENTS/BENEFITS FOR PURPOSES OF SYSTEM PLANNING AND DEVELOPMENT - OCEAN PHASE

Requirements	Measures of Minimum Performance Criteria to Meet Requirements									
	Accuracy (2 drms)									
	Predictable	Repeatable	Relative	Coverage	Availability	Reliability	Fix Rate	Fix Dimension	Capacity	Ambiguity
Safety of Navigation — All Craft	2-4NM(3.7-7.4km) Minimum 1-2NM(1.8-3.7km) DESIRABLE	—	—	Worldwide	95% full cap. 99% Fix at least every 12 hours	(2)	15 Mins. or Less Desired; 2 hrs Maximum	Two	Unlimited	Resolvable with 99% Confidence

Benefits	Measures of Minimum Performance Criteria to Achieve Benefits									
Large Ships Maximum Efficiency	0.1-0.25NM (185-460M) (1)	—	—	Worldwide, except Polar Regions	99%	(2)	5 min.	Two	Unlimited	Resolvable with 99% Confidence
Hydrography Science, Resource Exploitation	0.1-0.25NM (185-460M)	Maximum Possible	—	Worldwide	95%	(2)	1 min.	Two	Unlimited	Resolvable with 99% Confidence
Search Operations	0.25NM (460M.)	0.25NM	185 M.	National Maritime SAR Region (NPAC, NWLANT)	99%	(2)	1 min.	Two	Unlimited	Resolvable with 99% Confidence

(1) Requirement subject to confirmation by additional study
(2) Dependent upon mission time

reliably at intervals of a few hours at most. Even more so than with larger ships, this capability is particularly important in time of emergency or distress. Many (perhaps most) of these craft, however, will accept the risk of ocean sailing without reliable radionavigation unless that capability is available at relatively low cost.

Minimum Performance Criteria[5]

Economic efficiency in transoceanic transportation, special maritime activities and safety in emergency situations require or benefit from navigational accuracy higher than that needed for safety in routine, point-to-point ocean voyages. These requirements are summarized in Table 8-2. The predictable accuracy requirements may be as stringent as 0.1 nm for special maritime activities and large, economically efficient vessels; and may range to 0.25 nm for all of the above categories, including search operations. Search operations must also have a repeatable accuracy of at least 0.25 nm. As indicated in Table 8-2, the required fix rate may range from as low as once per five minutes to as high as one per minute. Signal availability must be at least 95 percent and approach 99 percent for search and rescue operations and large, high-efficiency ships. These requirements are based on current estimates and are to be used for the purpose of system planning. There have not been sufficient analyses to establish quantitative relationships between navigational accuracy and economic efficiency. The expensive, satellite-based navigation systems used by ships engaged in science and resource exploration, and the increasing use of relatively expensive satellite navigation by merchant ships and larger, ocean-going fishing vessels is evidence of the perceived value attached to highly accurate ocean navigation by the vessel owners.

8.3 U.S. MILITARY RADIONAVIGATION REQUIREMENTS[5]

The world-wide mission of the U.S. Military Forces requires accurate navigation within the Continental United States (CONUS), in oceanic areas, and in overseas theaters. A DoD classified supplement to the

Federal Radionavigation Plan provides specific service and Defense Mapping Agency (DMA) requirements for navigation and positioning accuracy organized by primary missions and functions and their related accuracy requirements in 2drms. These requirements are to be used for information and guidance in the development and procurement of military navigation systems.

9. INTERPRETATION OF ANALYSIS RESULTS

9.1 MEASURED 10.2 KHZ OMEGA COVERAGE

The OMEGA 10.2 kHz signal coverage results indicate that most areas of the North Atlantic have a minimum of four stations accessible during both summer and winter, day and night. Large areas have coverage from five stations during the day which is reduced to four station coverage during the night due to expected modal interference from Station B, Liberia. Some exceptions to this general coverage assessment were found which are consistent with the predicted coverage for the North Atlantic. These exceptions are identified in the following discussion.

The use of the OMEGA Navigation System generally requires the availability of signals from three or more stations. The 10.2 kHz coverage assessment shows that this requirement is being met in the North Atlantic with the exception of a few small areas. During summer day, 10.2 kHz signals from only two OMEGA transmitting stations are accessible in 1) the western part of the Gulf of Mexico, 2) a small triangular area between Norway and the United Kingdon, and 3) a semi-circular area within the near-field zone of the Norway Station. This condition also exists during daytime, both summer and winter, within the near-field zone of the Liberian Station.

Also, in er to provide a fail-soft feature (i.e. a backup station if one station is off-the-air), it is necessary to have four station coverage. Several areas have been identified which do not provide four station accessibility of the 10.2 kHz signals. These are:

Summer Day:
- a. Western Gulf of Mexico
- b. 55° - 70° N. Latitude, 45° W - 10° E Longitude
- c. Near-Field zone of Liberian station

Summer Night:
- a. Western Gulf of Mexico
- b. 10° - 40° N. Latitude, 65° - 75° W. Longitude
- c. Gulf of Guinea

Winter Day:	a. Mid-Gulf of Mexico b. Near-field zone of Liberian Station
Winter Night:	a. Western Gulf of Mexico b. 10° - 40° N. Latitude, 65° - 75° W. Longitude

9.2 COMPARISON OF MEASURED AND PREDICTED 10.2 KHZ COVERAGE

A comparison of the measured 10.2 kHz results with predicted coverage indicates the following:

Summer Local Noon

Station A - Norway: Measurements indicate that coverage extends further to the west than predicted, including the Caribbean Sea and the eastern part of the Gulf of Mexico. Although the NOSC test data were sparse in this region, measurements onboard the Anchorage in the eastern part of the Gulf during July 1978 indicated strong signal levels from Station A as far west as 81°. However, in the southeast sector of the North Atlantic coverage from Station A appears to be poorer than predicted.

Station B - Liberia: Measurements indicate that coverage is better than predicted in the southwest sector and poorer than predicted in the northwest sector.

Station C - Hawaii: Measurements indicate that coverage is as predicted in the northeast sector (i.e. the data shows the Greenland Shadow effect) and better than predicted off the west coast of Africa.

Station D - North Dakota: Measurements indicate that coverage is better than predicted in the northeast sector and as predicted in the southeast sector.

Station E - La Reunion: Measurements indicated that no coverage is provided, which substantiates predictions.

Station F - Argentina: Measurements indicate coverage as far north as 50° N. Latitude as compared to 20° N. Latitude from predictions.

Station H - Japan: The few measurements for this station do not contradict predictions.

Winter Local Midnight

Station A - Norway: Measurements indicate that coverage extends further west in the Gulf of Mexico than predicted.

Station B - Liberia: Predicted modal interference zone was confirmed as NOSC flight data through the area showed considerable signal instability.

Station C - Hawaii: Measurements indicate that coverage is as predicted.

Station D - North Dakota: Measurements indicate better coverage than predicted in the northeast sector.

Station E - La Reunion: Predicted modal interference zone was confirmed although there were very little data to either substantiate or contradict this.

Station F - Argentina: Predicted modal interference zone was rejected based on measurements made on east coast of U.S.

Station H - Japan: The few measurements for this station do not contradict predictions.

9.3 COVERAGE ASSESSMENT AT 13.6 KHZ

The OMEGA 13.6 kHz signal coverage results for summer day and winter night show improved signal coverage in all areas where the 10.2 kHz coverage does not meet the three station fix capability, except the western part of the Gulf of Mexico during summer day.

Further improvement is indicated in the four station availability fail-soft feature. At 13.6 kHz, the only areas where this feature is not provided are in the western part of the Gulf of Mexico, the southeast coast of Greenland and a small triangular area between Iceland and Norway during summer day; the southeast coast of Greenland and the extreme western part of the Gulf of Mexico during winter night.

9.4 MEASURED 10.2 KHZ FIX ACCURACY

Based on the fix accuracy analysis described in Section 6 of this report, zonal maps have been prepared which show the recommended LOP combinations in the North Atlantic. Zonal maps showing recommended LOP combinations based on the total error (D) are given in Figure 9-1 for summer day and Figure 9-2 for winter night. Similar type maps based on the 95% CEP figures are given in Figure 9-3 for summer day and Figure 9-4 for winter night.

In preparing these maps, the coverage criteria discussed earlier in the report was adhered to except along a small portion of the eastern coast of the United States between Massachusetts and Virginia. Here the accuracies were very poor for LOP combinations using C-D because this area is on or close to the C-D baseline extension. Although the Argentina (F) signal is expected to be modally disturbed in this area during nighttime, it appears that it would be preferable to use it instead of LOP C-D.

Average values of the total error (D) and the 95% CEP weighted by zonal area over the entire North Atlantic, based on the most accurate LOP combination in each zone, were calculated. These are:

	Fix Error in Nautical Miles	
	Total Error (D)	95% CEP
Summer Day	0.8	1.2
Winter Night	2.4	1.9

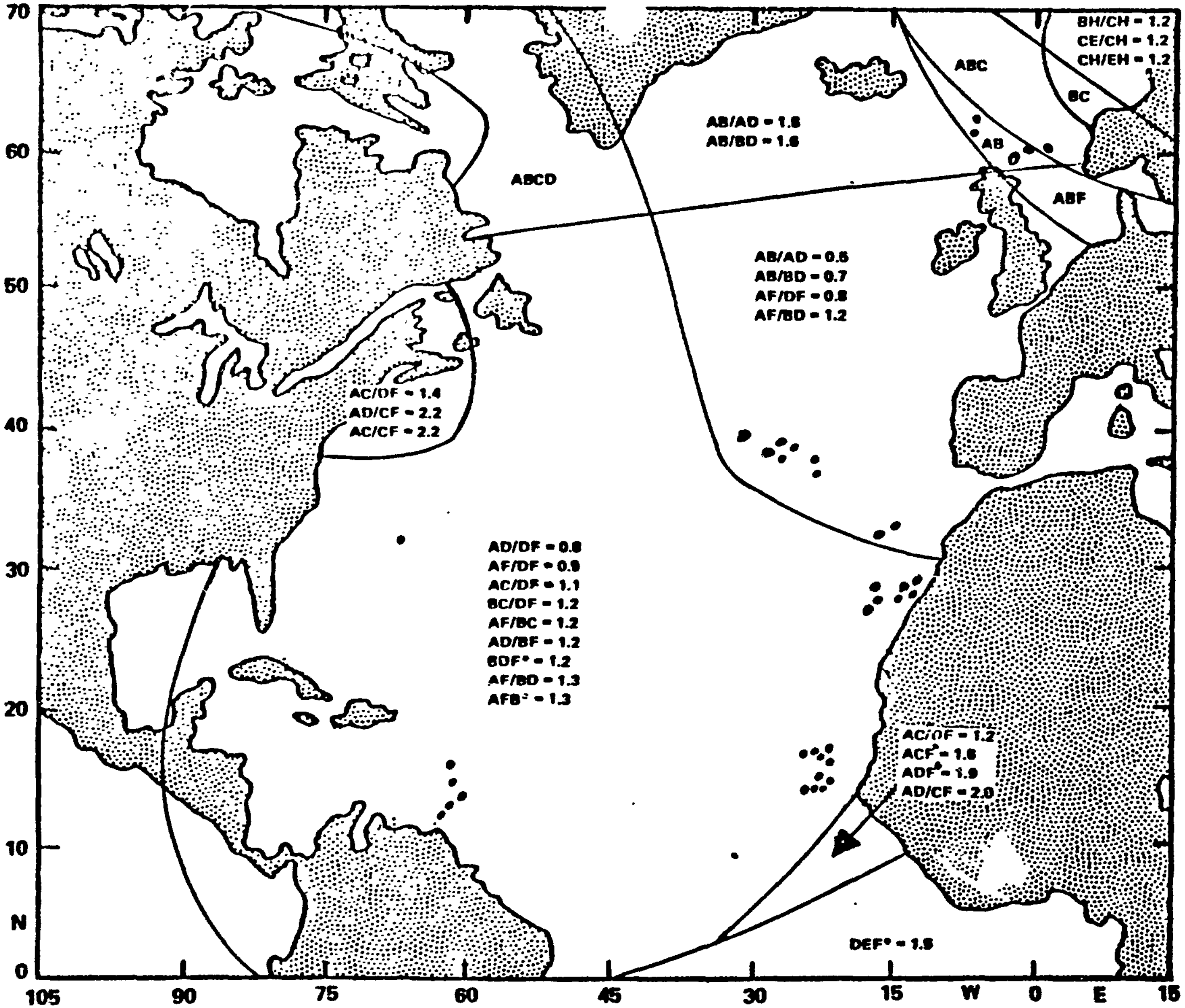
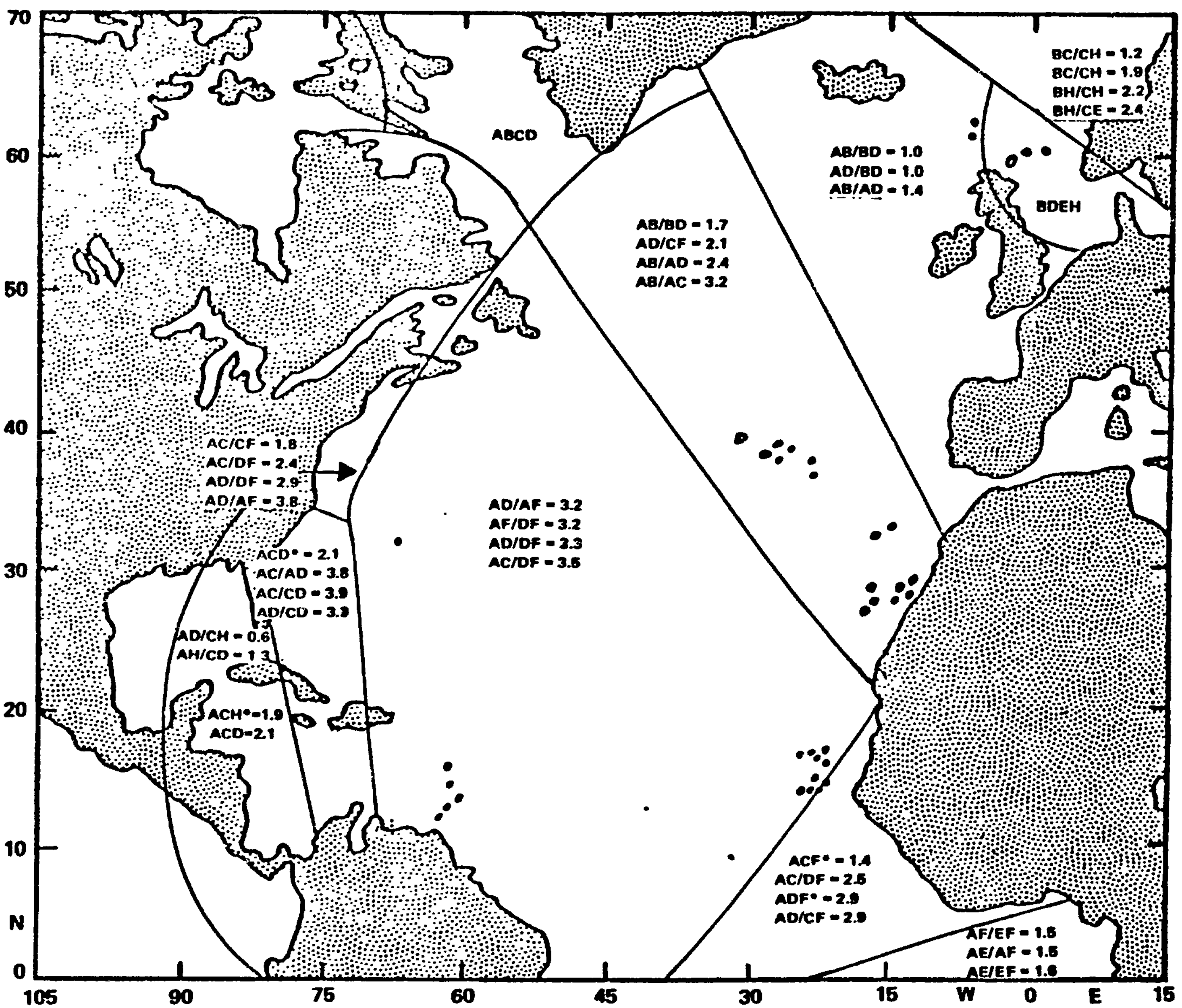


Figure 9-1 Recommended LOPs Based on Total Error (D),
Summer Day, 10.2 kHz



* SHIPBOARD DATA.
ALL COMBINATIONS
EQUAL.

Figure 9-2 Recommended LOPs Based on Total Error (D), Winter Nig 10.2 kHz

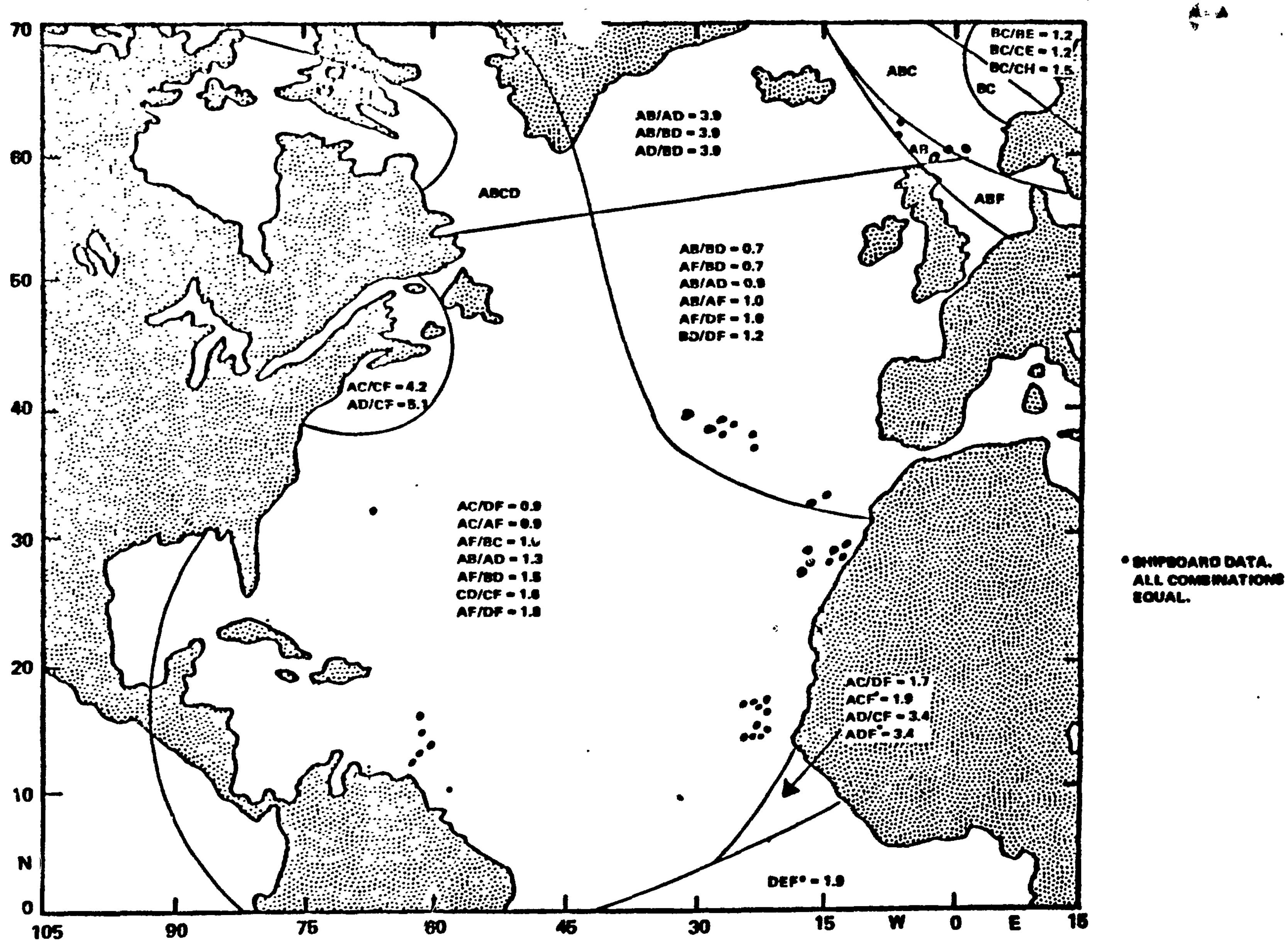


Figure 9-3 Recommended LOPs Based on 95% CEP, Summer Day, 10.2 kHz

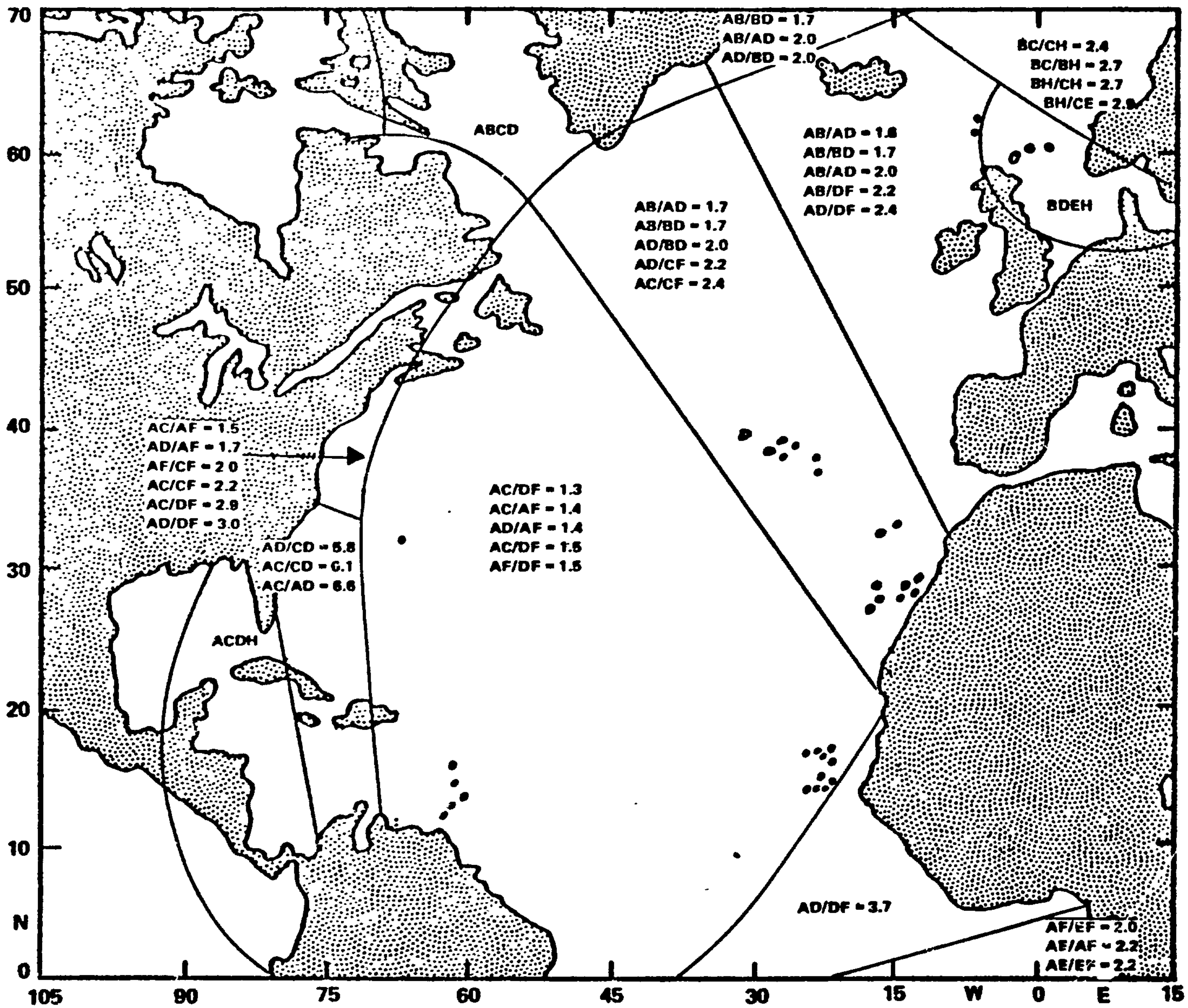


Figure 9-4 Recommended LOPs Based on 95% CEP, Winter N[illegible]t, 10.2 kHz

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

Conclusions drawn from the analysis of the data collected for the validation of the OMEGA Navigation System in the North Atlantic region can best be expressed in terms of coverage and accuracy being provided by the system.

10.1.1 Coverage

The use of the OMEGA Navigation System generally requires the availability of signals from three or more stations. The 10.2 kHz coverage assessment shows that this requirement is met in the North Atlantic with the exception of a few small areas. However, except for the western part of the Gulf of Mexico during summer day, the OMEGA 13.6 kHz signals provide adequate coverage for those areas not covered at 10.2 kHz. Also, the use of the 13.6 kHz signals greatly reduces the geographical areas which do not have a four station coverage fail-soft feature at 10.2 kHz.

The coverage analysis also confirmed 1.) the lack of usable signals from the La Reunion (E) and Japan (H) stations at all times in most of the North Atlantic, as predicted, and 2.) the dependence on the Norway (A) signals, especially in the northeastern sector during summer day when only three station coverage is indicated. Predictions show that when the Australia (G) station becomes operational, there will be a significant improvement in coverage in the Southeastern Atlantic, the Caribbean Sea and the Gulf of Mexico during nighttime conditions.

Conclusions relating to other features affecting coverage are given below.

Modal Interference

The NOSC airborne and ground station data confirmed the predicted 10.2 kHz nighttime modal interference zones in the North Atlantic for the Liberia (B) and Argentina (F) OMEGA stations. At 13.6 kHz, the data showed nighttime modal interference for Liberia very similar to the 10.2 kHz data except for flights between Liberia and Recife, Brazil where 13.6 kHz was more severly disturbed. However, the Argentina signals at 13.6 kHz were less modally disturbed than the 10.2 kHz signals along the southeastern coast of the United States.

Near Field Zones

The NOSC radial flights indicated that the extent of the near-field zone for Norway (A) is approximately 300 km (day) and 750 km (night) at 10.2 kHz and slightly larger at 13.6 kHz. Similar results were indicated for Liberia during the day, and the modal interference pattern at night encompasses the near-field zone.

Long Path

The La Reunion (E) signals at both 10.2 kHz and 13.6 kHz recorded along the east coast of the United States and in the Caribbean have been identified as long-path signals, i.e. signals propagating from along the longer of two great circle arcs between the transmitting station and the receiver. Such long-path signals cannot be used for navigating.

10.1.2 Fix Accuracy at 10.2 kHz

The characteristic accuracy of the OMEGA Navigation System as specified in the proposed Federal Radionavigation Plan [5] is:

Predictable Accuracy = 2-4 nm (2-drms)
Repeatable Accuracy = 2-4 nm (2-drms)
Relative Accuracy = 1-2 nm (2-drms)

The analysis results show that by using the most accurate LOP combination a total error (D) of 0.8 nm is achievable in the North Atlantic during summer day and 2.4 nm is achievable during winter night. Similarly, the 95% CEP achievable in the North Atlantic is 1.2 nm during summer day and 1.9 nm during winter night.

The 95% CEP figures are directly relatable to the required repeatable accuracy, expressed in terms of 2-drms. For a circular bivariate Gaussian distribution:

$$\begin{aligned}
\text{1-drms} &= \sqrt{2}\ \sigma_{\bar{r}} = 1.414\ \sigma_{\bar{r}} \\
\text{2-drms} &= 2.828\ \sigma_{\bar{r}} \\
\text{95\% CEP} &= 2.4478\ \sigma_{\bar{r}} \\
\text{2-drms} &= 1.155 \times \text{95\% CEP}
\end{aligned}$$

Thus the repeatable accuracy for the OMEGA Navigation System in the North Atlantic is 1.4 nm (2-drms) for summer day and 2.2 nm (2-drms) for winter night. This is clearly within the civil air user repeatable accuracy requirements of the MNPS, i.e. 2σ shall be less than 12.6 nm for the organized track system in the North Atlantic and the predictable accuracy of the civil marine requirements of 2-4 nm for safety at sea.

The total error (D) is a combination of the bias error (R) and the standard deviation of the radial error ($\sigma_{\bar{r}}$) and cannot be expressed in terms of 2-drms. It is, however, a measure of the predictable error and has been used in this study to better define the OMEGA system for the user. The bias error (R) is almost entirely due to PPC error and therefore most of this error can be removed by PPC adjustments.

A bias error analysis (Section 6.3) indicates that consistent phase difference biases are being measured at a number of the North Atlantic ground monitor sites.

10.2 RECOMMENDATIONS

Three recommendations have resulted from this assessment of the coverage and accuracy being provided by the OMEGA Navigation System in the North Atlantic. These recommendations are:

- To investigate the efficacy of the -20dB SNR (100 Hz B.W.) criterion for signal coverage. New technology being implemented in receiver design offers an increase in receiver sensitivity for acquiring OMEGA signals, and an increase in noise reduction through new processing techniques. A relaxation in the criterion for signal coverage from -20 dB SNR to -30 dB SNR will result in a significant improvement in signal coverage for new technology receivers. Consistent with ths advance in receiver technology, new signal coverage diagrams should be published which show SNR threshold contours at -30 dB.

- To remove bias errors through PPC improvements as soon as possible. The results included in this report indicate that the bias errors due to PPC corrections are normally greater than the random errors and form a major portion of the overall error. More specifically, elimination of the PPC errors of the type described in Table 6.5 of this report would result in at least a 30% improvement in overall accuracy (D). Improved propagation corrections should be developed in order that this improvement can be realized.

- To recommend the use of multi-frequency receivers for improved coverage and accuracy. Analyses described in this report indicate that the use of 13.6 kHz signals improves signal coverage substantially. The OMEGA Navigation System offers additional frequencies which may be utilized to improve coverage and accuracy further. Signal coverage diagrams and propagation corrections should be developed for these additional frequencies.

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APPENDIX A

Transmitter Monitor Station Data

The tables in this section list the measured 10.2 kHz data at each of the transmitter monitor sites. The time of day is indicated for each block of data and flags are shown appropriately. The definitions of the flags are as follows:

S - Data block failed phase error variance test

Q - Insufficient data in block for phase error variance test

B - Large phase error bias for data block

E - Large rms phase error for data block

F - All data in block are flagged

In processing these data to assess fix accuracy, both unflagged monthly data blocks and monthly data blocks flagged S, Q, B, and E were used. Data blocks flagged F were not used.

Within each data block there are also daily/hourly flags (i.e. SID, PCA, transmitter out, monitor out etc). These flagged data were not used in the fix-accuracy calculations.

The following tables are included:

Table A-1 (A-C)	Hestmona, Norway
Table A-2 (A-B)	La Moure, North Dakota
Table A-3	Monrovia, Liberia
Table A-4 (A-B)	Piarco, Trinidad
Table A-5 (A-B)	Trinidad, Site 2

TABLE A-1-A

FIXED MONITOR: *HESTMONA, NORWAY* FREQUENCY: 10.2 kHz

YR.	MO.	STATION A	B	C	D	E	F	G	H
1967	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN			D^B					
	JUL			D					
	AUG			D^B					
	SEP			T^B					
	OCT			T					
	NOV			T					
	DEC			N					
1968	JAN			T					
	FEB			T					
	MAR			T					
	APR			D					
	MAY			D					
	JUN			D					
	JUL			D					
	AUG			D^B					
	SEP			T^B					
	OCT			T					
	NOV			T					
	DEC			N					

YR.	MO.	STATION A	B	C	D	E	F	G	H
1969	JAN			T					
	FEB			T					
	MAR			T					
	APR			D^B					
	MAY			D^B					
	JUN			D					
	JUL			D					
	AUG			D					
	SEP			T^B					
	OCT			T^B					
	NOV			T					
	DEC			N					
1970	JAN			T					
	FEB			T					
	MAR			T^B					
	APR			D					
	MAY			D					
	JUN			D					
	JUL			D					
	AUG								
	SEP			T^B					
	OCT			T					
	NOV			T					
	DEC			N					

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABI \-1-B

5620

FIXED MONITOR: HESTMONA, NORWAY

FREQUENCY: 10.2 kHz

YR.	MO.	STATION A	B	C	D	E	F	G	H
1971	JAN			T					
	FEB			T					
	MAR			T					
	APR			D					
	MAY			D B					
	JUN			D					
	JUL			D					
	AUG			D					
	SEP			T B					
	OCT			T S					
	NOV			T B					
	DEC			N					
1972	JAN			T					
	FEB			T					
	MAR			T					
	APR			D					
	MAY			D					
	JUN			D					
	JUL			D					
	AUG			D B					
	SEP			T B					
	OCT			T					
	NOV			T	N B				
	DEC			N	N B				

YR.	MO.	STATION A	B	C	D	E	F	G	H
1973	JAN			T	N B				
	FEB			T	N B				
	MAR				D/N B				
	APR				T				
	MAY				D B				
	JUN				D B				
	JUL				D B				
	AUG				T B				
	SEP								
	OCT								
	NOV								
	DEC				N B				
1974	JAN								
	FEB				N B				
	MAR				D/N B				
	APR				D B				
	MAY				D B				
	JUN				D B				
	JUL				D B				
	AUG				D B				
	SEP				T B				
	OCT				D/N B				
	NOV			T	N B				
	DEC			N	N B				

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;

TABLE A-1-C

5620

FIXED MONITOR: Hestmona, Norway   FREQUENCY: 10.2 kHz

YR.	MO.	STATION A	B	C	D	E	F	G	H
1975	JAN			T	N^B				
	FEB			T	N^B				
	MAR			T	D/N^B				
	APR			D^B	D^B				
	MAY			D^B	D^B				
	JUN			D	D^B				
	JUL			D	D^B				
	AUG			D^B	D^B				
	SEP			T^B					
	OCT			T^B	N^B				N^B
	NOV			T^S	N^B				N^B
	DEC			T^S	T^F				N^B
1976	JAN			T^S	T^B				N^B
	FEB		D/N^B	T^B	N^B				N^B
	MAR			T	N^B				D/N^B
	APR			D^B	D^B				D^B
	MAY		D	D^B					D^B
	JUN		D	D^B					D^B
	JUL		D^B	D^B		D/N^B			D^B
	AUG		D^B	D^B		D^B			D^B
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	STATION A	B	C	D	E	F	G	H
1977	JAN								
	FEB								
	MAR								
	APR		D/N	D^B		D/N^B			
	MAY		D/N	D^B		D/N^E			D^B
	JUN		D/N	D^B		D/N^S			D^B
	JUL								
	AUG		D/N^B	D^B		D/N^B			D^B
	SEP		D/N	T^B		D/N^S			D^B
	OCT		D/N^B	T		D/N^S			D/N^B
	NOV		D/N^S	T		D/N^S			N^B
	DEC		N^S	N		N^S			N^B
1978	JAN								
	FEB		N^B	T		N^B			N^B
	MAR		D/N^B	T		D/N^S			D/N^B
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE A-2-A

5820

FIXED MONITOR: La Moure, N. Dakota, U.S.A. FREQUENCY: 10.2 kHz

YR.	MO.	STATION A	B	C	D	E	F	G	H
1973	JAN								
	FEB								
	MAR	D/N							
	APR	T^{S}							
	MAY	D^{B}							
	JUN	D^{B}							
	JUL	D^{B}							
	AUG	D^{B}							
	SEP								
	OCT								
	NOV								
	DEC	N^{S}							
1974	JAN	N							
	FEB	N							
	MAR	D/N							
	APR	D^{B}							
	MAY	D^{B}							
	JUN	D^{B}							
	JUL	D^{E}							
	AUG	D^{B}							
	SEP	T^{B}							
	OCT	D/N^{B}							
	NOV	N^{B}		D/N					
	DEC	N^{B}		D/N					

YR.	MO.	STATION A	B	C	D	E	F	G	H
1975	JAN	N^{B}							
	FEB	N^{B}		D/N					
	MAR	D/N		D/N					T^{S}
	APR			D/N					
	MAY			D/N					D^{B}
	JUN	D^{B}		D/N					D^{B}
	JUL	D^{B}		D/N					D^{B}
	AUG	D^{B}		D/N					D^{B}
	SEP								
	OCT	D/N		D/N					N^{B}
	NOV	N		D/N					N^{B}
	DEC	N		D/N					N^{B}
1976	JAN	N		D/N					N^{B}
	FEB	N^{B}		D/N					N^{B}
	MAR	N^{B}		D/N					T^{B}
	APR	D^{B}		D/N					D^{B}
	MAY	D^{B}		D/N					
	JUN			D/N			D/N^{S}		D/N^{B}
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE A-2-B

5620

FIXED MONITOR: LA MOURE, N. DAKOTA, U.S.A.   FREQUENCY: 10.2 kHz

YR.	MO.	STATION A	B	C	D	E	F	G	H
1977	JAN			D/N			D/N^{S}		N^{B}
	FEB			D/N			D/N^{S}		N^{B}
	MAR			D/N			D/N		N^{B}
	APR						D/N^{S}		N
	MAY								
	JUN			D/N			D/N^{S}		D
	JUL								
	AUG								
	SEP			D/N			D/N^{S}		T^{B}
	OCT								
	NOV								
	DEC			D/N			D/N^{S}		N^{B}
1978	JAN								
	FEB			D/N			D/N^{S}		T^{B}
	MAR			D/N			T^{F}		D^{B}
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	STATION A	B	C	D	E	F	G	H
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE A-3

6820

FIXED MONITOR: Monrovia, Liberia

FREQUENCY: 10.2 kHz

YR.	MO.	STATION A	B	C	D	E	F	G	H
1976	JAN								
	FEB	D/N^{B}							
	MAR	N^{B}							
	APR	D/N^{S}							
	MAY								
	JUN	D^{E}					D/N^{S}		
	JUL	D^{S}				D/N^{S}	D/N^{S}		
	AUG	D^{S}				D/N^{S}	D/N^{B}		
	SEP								
	OCT								
	NOV								
	DEC								
1977	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP	D/N^{S}				D/N^{B}	D/N^{B}		
	OCT	D/N^{B}					D/N^{B}		
	NOV								
	DEC	N^{B}				D/N^{S}	D/N^{B}		

YR.	MO.	STATION A	B	C	D	E	F	G	H
1978	JAN								
	FEB	N^{B}				D/N^{B}	D/N^{B}		
	MAR	D/N^{S}				D/N^{B}	T^{F}		
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, Q, B, E, F - See accompanying description

TABLE A-4-A

5620

FIXED MONITOR: PIARCO, TRINIDAD

FREQUENCY: 10.2 kHz

YR.	MO.	STATION A	B	C	D	E	F	G	H
1971	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP	D/N		D/N					
	OCT								
	NOV								
	DEC								
1972	JAN	D/N		D/N^B					
	FEB	D/N		D/N					
	MAR	D/N		D/N					
	APR	D/N		D/N					
	MAY	D		D/N					
	JUN								
	JUL	D		D/N					
	AUG	D		D/N					
	SEP	D/N^B		D/N					
	OCT	D/N^B		D/N					
	NOV	D/N		D/N	D/N				
	DEC	N		D/N	D/N				

YR.	MO.	STATION A	B	C	D	E	F	G	H
1973	JAN	D/N		D/N					
	FEB	D/N		D/N^B	D/N				
	MAR	D/N			D/N				
	APR	D/N^B			D/N				
	MAY	D^B			D/N				
	JUN	D^B			D/N				
	JUL	D			D/N				
	AUG				D/N				
	SEP				D/N				
	OCT				D/N				
	NOV				D/N				
	DEC	N			D/N				
1974	JAN	D/N			D/N				
	FEB				D/N				
	MAR	D/N			D/N				
	APR	D/N			D/N				
	MAY	D^B			D/N				
	JUN	D^B			D/N				
	JUL	D^B			D/N				
	AUG	D			D/N				
	SEP	N^B			D/N				
	OCT	D/N^B			D/N				
	NOV				D/N				
	DEC								

LEGEN' D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE A-4-B

5820

FIXED MONITOR: Piarco, Trinidad

FREQUENCY: 10.2 kHz

YR.	MO.	A	B	C	D	E	F	G	H
1975	JAN								
	FEB	D/N		T^B	D/N				
	MAR								
	APR								
	MAY								
	JUN	D		D/N	D/N				
	JUL	D		D/N	D/N				
	AUG	D		D/N	D/N				
	SEP	D/N		D/N					
	OCT	D/N		D/N	D/N				
	NOV	D/N		D/N	D/N				
	DEC	N		T^B	D/N				
1976	JAN			T^B	D/N				
	FEB		D/N^B		D/N				
	MAR		D/N^B		D/N				
	APR		D/N^B		D/N				
	MAY		D/N^B		D				
	JUN		D/N^B		D				
	JUL		D/N^B		D/N				
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	A	B	C	D	E	F	G	H
1977	JAN		D/N^B		D/N				
	FEB		D/N^B		D/N				
	MAR								
	APR		D/N^B						
	MAY		D/N^B						
	JUN		D/N^B		D/N				
	JUL								
	AUG								
	SEP		D/N^B		D/N				
	OCT		D/N^B		T				
	NOV								
	DEC		D/N^B		D/N				
1978	JAN								
	FEB		D/N^B		D/N				
	MAR		D/N^B		D/N				
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE A-5-A

6620

FIXED MONITOR: TRINIDAD, SITE 2 FREQUENCY: 10.2 kHz

YR.	MO.	A	B	C	D	E	F	G	H
1967	JAN								
	FEB								
	MAR								
	APR	D/N		D/N					
	MAY	D		D/N					
	JUN	D[B]		D					
	JUL	D		D					
	AUG	D		D/N					
	SEP	D/N		D/N					
	OCT	D/N		D/N					
	NOV	D/N		D/N					
	DEC	N[B]		D/N					
1968	JAN	D/N		D/N					
	FEB	D/N[B]		D/N					
	MAR	D/N		D/N					
	APR	D/N		D/N					
	MAY								
	JUN	D		D/N					
	JUL	D		D/N					
	AUG	D		D/N					
	SEP	D/N[B]		D/N					
	OCT	D/N[B]		D/N					
	NOV	D/N[B]		D/N					
	DEC	N		D/N					
1969	JAN	D/N		D/N					
	FEB	D/N		D/N					
	MAR	D/N		D/N					
	APR	D/N[B]		D/N					
	MAY	D[B]		D/N					
	JUN	D[B]		D/N					
	JUL	D		D/N					
	AUG	D		D/N					
	SEP	D/N		D/N					
	OCT	D/N[B]		D/N					
	NOV	D/N		D/N					
	DEC	N		D/N					
1970	JAN	D/N		D/N					
	FEB	D/N		D/N					
	MAR	D/N[B]		D/N					
	APR	D/N		D/N					
	MAY	D		D/N					
	JUN	D		D/N[B]					
	JUL	D[B]		D/N					
	AUG	D/N		D/N					
	SEP	D/N		D/N					
	OCT	D/N		D/N					
	NOV	D/N		D/N					
	DEC	N		D/N					

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE A-5-B

5620

FIXED MONITOR: Trinidad, Site 2

FREQUENCY: 10.2 kHz

YR.	MO.	STATION A	B	C	D	E	F	G	H
1971	JAN								
	FEB	D/N		D/N					
	MAR	D/N		D/N					
	APR	D/N		D/N					
	MAY	D B		D/N					
	JUN	D		D/N					
	JUL	D		D/N					
	AUG	D		D/N					
	SEP								
	OCT	D/N B		D/N B					
	NOV	D/N B		D/N B					
	DEC	N B		D/N B					
1972	JAN	D/N B		D/N B					
	FEB	D/N B		D/N B					
	MAR	D/N B		D/N B					
	APR	D/N B		D/N B					
	MAY								
	JUN	D B		D/N B					
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	STATION A	B	C	D	E	F	G	H
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

APPENDIX B

Ground Monitor Station Data

The tables in this section list the measured 10.2 kHz data at each of the ground monitor sites. The time of day is indicated for each block of data and flags are shown appropriately. The definitions of the flags are as follows:

S - Data block failed phase error variance test

Q - Insufficient data in block for phase error variance test

B - Large phase error bias for data block

E - Large rms phase error for data block

F - All data in block are flagged.

In processing these data to assess fix-accuracy, both unflagged monthly data blocks and monthly data blocks flagged S, Q, B and E were used. Data blocks flagged F were not used.

Within each data block there are also daily/hourly flags (i.e., SID, PCA, transmitter out, monitor out etc). These flagged data were not used in the fix-accuracy calculations.

The following tables are included:

Table B-1		Belem, Brazil
Table B-2	(A-C)	Bermuda
Table B-3		Cambridge, MA., U.S.A.
Table B-4		Coral Harbor, Canada
Table B-5		Eglin AFB, FLA., U.S.A.
Table B-6	(A-B)	Farnborough, U.K.
Table B-7		Frobisher, Canada

TABLE B-1

FIXED MONITOR: BELEM, BRAZIL

FREQUENCY: 10.2 kHz

YR.	MO.	LOP AC	LOP AD	LOP CD					
1974	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN		D						
	JUL		D						
	AUG		D						
	SEP								
	OCT		D/N						
	NOV		N^B						
	DEC	N^B	N^B	D/N^B					
1975	JAN	T^B	N	D/N^B					
	FEB	T^B	N	D/N					
	MAR	T^S	D/N	D/N^B					
	APR	D/N^S	D	D/N					
	MAY	D^B	D	D/N^B					
	JUN	D^B	D	D/N^B					
	JUL	D^B	D	D/N^B					
	AUG	D^S	D	D/N					
	SEP	T^S							
	OCT	T^S	D/N	D/N					
	NOV	T^S	N	D/N					
	DEC	N^B	N	D/N					

YR.	MO.	LOP AC	LOP AD	LOP CD					
1976	JAN	T^B	N	D/N^B					
	FEB	T^B	N	D/N^B					
	MAR	T^S	N^B	D/N^B					
	APR	D^B	D	D/N^B					
	MAY	D^B	D	D/N^B					
	JUN	D^B	D	D/N^B					
	JUL	D^B	D	D/N^B					
	AUG	D^S	D	D/N^B					
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE B-2-A

5620

FIXED MONITOR: BERMUDA

FREQUENCY: 10.2 kHz

YR.	MO.	LOP AC							
1966	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT	D/N							
	NOV								
	DEC								
1968	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV	T							
	DEC	N							

YR.	MO.	LOP AC							
1969	JAN	T							
	FEB	T							
	MAR	T							
	APR	D							
	MAY	D B							
	JUN	D							
	JUL	D							
	AUG	D							
	SEP	T							
	OCT	T							
	NOV	T							
	DEC	N							
1970	JAN	T							
	FEB	T							
	MAR	T							
	APR	D							
	MAY	D							
	JUN	D							
	JUL	D							
	AUG								
	SEP	T							
	OCT	T							
	NOV	T							
	DEC	N							

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE B-2-B

6620

FIXED MONITOR: BERMUDA

FREQUENCY: 10.2 kHz

YR.	MO.	LOP AC	AD						
1971	JAN	T							
	FEB	T^B							
	MAR	T							
	APR	D^B							
	MAY	D							
	JUN	D							
	JUL	D							
	AUG	D							
	SEP	T^B							
	OCT	T							
	NOV	T^S							
	DEC	N							
1972	JAN	T^S							
	FEB	T^S							
	MAR	T^S							
	APR	T^S							
	MAY	D							
	JUN	D							
	JUL	D							
	AUG	D^B							
	SEP	T^B							
	OCT	T^B							
	NOV	T^S	N^S						
	DEC	T^S	N						

YR.	MO.	LOP AC	AD						
1973	JAN								
	FEB	T	N						
	MAR		D/N						
	APR		D						
	MAY		D						
	JUN		D						
	JUL		D						
	AUG		T						
	SEP								
	OCT								
	NOV								
	DEC		T						
1974	JAN		N						
	FEB		N						
	MAR		D/N^B						
	APR		D^S						
	MAY		D						
	JUN		D						
	JUL		D^B						
	AUG		D^B						
	SEP		T^S						
	OCT		D/N^S						
	NOV	T^S	N^S						
	DEC	N^S	N^S						

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, Q, B, E, F - See accompanying description

5820

TABLE B-2-C

FIXED MONITOR: BERMUDA

FREQUENCY: 10.2 kHz

YR.	MO.	LOP AC	AD	AF	BC	BD	DF		
1975	JAN	T^S	N^S						
	FEB	T^S	N						
	MAR	T^B							
	APR	D^B	D						
	MAY	D^S	D						
	JUN	D^S							
	JUL								
	AUG	D^S	D^S						
	SEP	T^S							
	OCT								
	NOV								
	DEC								
1977	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV	T^S	T^S	N^B	T^S	T^S	D^S		
	DEC								

YR.	MO.	LOP AC	AD	AF	BC	BD	DF		
1978	JAN								
	FEB								
	MAR								
	APR								
	MAY	T^B	T^F	T^F	D^S	N^S	D/N^B		
	JUN								
	JUL	D^S	D^S	D^B	D^E	D^S	D^B		
	AUG	T^F	T^F	T^F	T^F	T^F	T^F		
	SEP	T^E	D^E	D^S	D^B	D/N^E	D/N^B		
	OCT								
	NOV	T^E	N^E	D/N^S	T^E	D/N^B	D/N^E		
	DEC	N^E	N^E	N^E	T^E	D/N^B	D/N^B		
1979	JAN	T^E	N^E	N^E	T^E	D/N^B	D/N^B		
	FEB								
	MAR	T^F	N^B	T^F	T^B	D/N^S	N^S		
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE B-3

5620

FIXED MONITOR: CAMBRIDGE, MA., U.S.A.

FREQUENCY: 10.2 kHz

YR.	MO.	LOP							
		AC							
1968	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV	T							
	DEC	N							
1969	JAN	T							
	FEB	T							
	MAR	T^B							
	APR	D^B							
	MAY	D							
	JUN	D							
	JUL	D							
	AUG	D							
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
		AC	AD	AF	CD	CF			
1978	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL	D^S	D^S	T^S	T^S	T^S			
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
1979	JAN	T^S	N^S	T^S	D/N^S	T^S			
	FEB	T^E	N^B	D/N^B	D/N^E	D/N^E			
	MAR	T^B	D^B	D/N^B	D/N^E	D/N^E			
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;

TABLE B-4

5820

FIXED MONITOR: Coral Harbor, Canada FREQUENCY: 10.2 kHz

YR.	MO.	LOP							
		AC							
1971	JAN	T S							
	FEB	T							
	MAR	T S							
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV	T							
	DEC	N							
1972	JAN	T							
	FEB	T							
	MAR	T							
	APR	D							
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT	T E							
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;

TABLE B-5

5820

FIXED MONITOR: EGLIN AFB, FLA., U.S.A.　　FREQUENCY: 10.2 kHz

YR.	MO.	LOP AC	AD	CD	CF	CH	DH		
1977	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL	T^F	T^F	T^F	T^F	T^F	T^F		
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
1978	JAN								
	FEB	T^F	T^F	D/N^B	T^S	T^F	T^F		
	MAR	T^S	T^S	D/N^B	T^F	T^S	T^S		
	APR								
	MAY								
	JUN	T^F	T^F	D/N	D/N^S	T^F	T^F		
	JUL	D^S	D^S	D/N	D/N^S	T^F	T^F		
	AUG								
	SEP	T^S	T^S	D/N	D/N^S	T^F	T^F		
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP AC	AD	CD	CF	CH	DH		
1979	JAN	T^S	D^S	D/N	D^S	T^F	T^F		
	FEB	T^S	N^S	D/N	D/N^S	T^F	T^F		
	MAR	T^F	N^B	D/N	D/N^S	T^F	T^F		
	APR	T^S	T^S	D/N	D/N^S	T^F	T^F		
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, Q, B, E, F - See accompanying description

TABLE B-6-A

5620

FIXED MONITOR: FARNBOROUGH, U.K.   FREQUENCY: 10.2 kHz

YR.	MO.	LOP							
		AD							
1972	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC	N^{B}							
1973	JAN								
	FEB								
	MAR								
	APR								
	MAY	D^{B}							
	JUN	D^{B}							
	JUL	D^{B}							
	AUG	T^{B}							
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
		AD							
1974	JAN	N							
	FEB	N^{B}							
	MAR	D/N^{B}							
	APR	D^{B}							
	MAY	D^{B}							
	JUN	D^{B}							
	JUL	D^{B}							
	AUG	D							
	SEP	T^{B}							
	OCT	D/N^{B}							
	NOV	N^{B}							
	DEC	N^{B}							
1975	JAN								
	FEB	N^{B}							
	MAR								
	APR	D^{B}							
	MAY	D^{B}							
	JUN	D^{B}							
	JUL	D^{B}							
	AUG	D^{B}							
	SEP								
	OCT	N^{B}							
	NOV	N^{B}							
	DEC	N^{B}							

LEGEND: [illegible] - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE B-6-B

5620

FIXED MONITOR: FARNBOROUGH, U.K.

FREQUENCY: 10.2 kHz

YR.	MO.	LOP							
		AD	AB						
1976	JAN	N^{B}							
	FEB	N^{B}	D/N^{B}						
	MAR	N^{B}	N^{B}						
	APR	D	D/N^{E}						
	MAY	D	D^{B}						
	JUN	D	D^{B}						
	JUL	D	D^{B}						
	AUG	D	D^{B}						
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, Q, B, E, F - See accompanying description.

TABLE B-7

6820

FIXED MONITOR: FROBISHER BAY, CANADA

FREQUENCY: 10.2 kHz

YR.	MO.	LOP							
		AC	BD	CD	CF	DF	DH		
1977	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC	N	N^S	N^B	T^F	T^S	N^B		
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: [illegible] - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
[illegible] B, C, D, E, F - See accompanying description

TABLE B-8

6620

FIXED MONITOR: HAMMERFEST, NORWAY

FREQUENCY: 10.2 kHz

YR.	MO.	LOP							
		AC							
1968	JAN	T^B							
	FEB	T^B							
	MAR	T							
	APR	T							
	MAY	D^B							
	JUN	D^B							
	JUL	D^B							
	AUG	D^B							
	SEP	T^B							
	OCT	T^B							
	NOV	T^B							
	DEC	N^B							
1969	JAN	T^B							
	FEB	T							
	MAR	T^B							
	APR	T^B							
	MAY	D^B							
	JUN	D							
	JUL								
	AUG								
	SEP	T^B							
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	CCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE B-9

5620

FIXED MONITOR: KEFLAVIK, ICELAND

FREQUENCY: 10.2 kHz

YR.	MO.	LOP AB	AD	AE	BD	BF	DF		
1977	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC	N	N	N	N^B	D^B	T^S		
1978	JAN								
	FEB								
	MAR								
	APR	T^F	T^F	T^F	T^F	T^F	T^F		
	MAY								
	JUN								
	JUL	D/N	D^B	T^F	D^B	D/N^E	D^S		
	AUG	T^F	T^F	T^F	D	D/N^B	D^E		
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, Q, B, E, F - See accompanying description

TABLE B-10

5620

FIXED MONITOR: LAJES, AZORES

FREQUENCY: 10.2 kHz

YR.	MO.	LOP AB	LOP AC	LOP AD	LOP CD	LOP CF	LOP EF	LOP	LOP
1978	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL	D/N	D^B	D	D^B	D^S	N^B		
	AUG								
	SEP	T^F	T^F	T^F	T^F	T^F	T^F		
	OCT								
	NOV								
	DEC								
1979	JAN	D/N^S	T^S	N	N	N^E	D^E		
	FEB	D/N^B	T^S	N	N^S	N^S	D^E		
	MAR	T^S	T^S	D^S	D^S	D^S	D^E		
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND. D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE B-11

5620

FIXED MONITOR: MIAMI, FLA., U.S.A.

FREQUENCY: 10.2 kHz

YR.	MO.	LOP							
		AC							
1971	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP	T^B							
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;

TABLE B-12-A

6620

FIXED MONITOR: NEA MAKRI, GREECE

FREQUENCY: 10.2 kHz

YR.	MO.	LOP AD	AH	AB	BH	AF	AE	BD	
1975	JAN								
	FEB								
	MAR								
	APR								
	MAY	T	D^{B}						
	JUN	T^{B}	D						
	JUL								
	AUG								
	SEP	T^{S}	D						
	OCT	N	N						
	NOV	N	N						
	DEC	N	N						
1976	JAN	N^{S}	N^{E}						
	FEB	N	N	D/N	T^{B}				
	MAR	N^{S}			T^{B}				
	APR	T^{B}	D^{B}	D/N	T^{B}				
	MAY			D					
	JUN			D		D/N^{B}			
	JUL			D		D/N^{B}			
	AUG			D^{B}		D/N^{B}			
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP AD	AH	AB	BH	AF	AE	BD	
1977	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP	T^{F}		T^{S}	T^{S}	T^{F}	T^{F}	T^{F}	
	OCT								
	NOV	N^{S}		D/N^{S}	N^{B}	T^{S}	D/N^{S}	N^{S}	
	DEC								
1978	JAN	N^{B}		D/N^{S}	T^{S}	T^{S}	D^{S}	T^{S}	
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL	T^{F}		T^{F}	D	T^{F}	T^{F}	T^{F}	
	AUG	D		D/N	D^{B}	D/N^{E}	D/N	D^{S}	
	SEP								
	OCT								
	NOV								
	DEC	N		N^{B}	N^{B}	N^{E}	N	N	

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, Q, B, E, F - See accompanying description

5620

TABLE B-12-B

FIXED MONITOR: NEA MAKRI, GREECE

FREQUENCY: 10.2 kHz

YR.	MO.	LOP AD	LOP AH	LOP AB	LOP BH	LOP AF	LOP AE	LOP BD	LOP
1979	JAN	N		D/N	N^{S}	D/N^{E}	D/N	N	
	FEB	N		D/N	N^{B}	D/N^{E}	D/N^{B}	N	
	MAR								
	APR	T[illegible]		T^{F}	D^{B}	T^{F}	T^{F}	T^{F}	
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE B-13

5620

FIXED MONITOR: NELC, SAN DIEGO, CA., U.S.A.

FREQUENCY: 10.2 kHz

YR.	MO.	LOP							
		BF	CD	DH	EF				
1972	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV		D^B						
	DEC								
1976	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL	D/N^S	D/N	D	D^S				
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, Q, B, E, F - See accompanying description

TABLE B-14-A

5620

FIXED MONITOR: NORFOLK, COMOPTEVFOR

FREQUENCY: 10.2 kHz

YR.	MO.	LOP AC							
1971	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG	D							
	SEP								
	OCT								
	NOV								
	DEC								
1972	JAN	T							
	FEB	T							
	MAR	T							
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT	T							
	NOV	T							
	DEC								

YR.	MO.	LOP AC	AD						
1973	JAN	T							
	FEB	T							
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
1974	JAN		N						
	FEB		N						
	MAR		D/N						
	APR		D						
	MAY		D^{B}						
	JUN		D^{B}						
	JUL								
	AUG		D^{B}						
	SEP								
	OCT		D/N						
	NOV		N						
	DEC								

LEGEND: - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE B-14-B

5620

FIXED MONITOR: NORFOLK, COMOPTEVFOR

FREQUENCY: 10.2 kHz

YR.	MO.	LOP							
		AC	AD						
1975	JAN								
	FEB								
	MAR		D/N						
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T Transition Only;
Flags S, Q, B, E, F - See accompanying description

TABLE B-15

5620

FIXED MONITOR: NRL, WASHINGTON, D.C.

FREQUENCY: 10.2 kHz

YR.	MO.	LOP AC							
1967	JAN								
	FEB								
	MAR								
	APR								
	MAY	D^B							
	JUN	D^B							
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
1968	JAN								
	FEB								
	MAR	T							
	APR	D							
	MAY	D							
	JUN	D							
	JUL	D							
	AUG	D							
	SEP	T							
	OCT								
	NOV	T							
	DEC	N							

YR.	MO.	LOP AC							
1969	JAN	T							
	FEB	T							
	MAR	T^B							
	APR	D^E							
	MAY	D^B							
	JUN	D^B							
	JUL	D							
	AUG	D^B							
	SEP	T							
	OCT	T							
	NOV	T							
	DEC	N							
1970	JAN	T^B							
	FEB	T^B							
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: ' - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE B-16

5620

FIXED MONITOR: OSLO (2), NORWAY

FREQUENCY: 10.2 kHz

YR.	MO.	LOP							
		AC							
1971	JAN	T							
	FEB	T							
	MAR								
	APR	D							
	MAY	D							
	JUN	D							
	JUL	D							
	AUG	D							
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, Q, B, E, F - See accompanying description

TABLE B-17

5620

FIXED MONITOR: PANAMA

FREQUENCY: 10.2 kHz

YR.	MO.	LOP AD	BD	CD	CF	CH	DH		
1978	JAN	T^S	T^S	T^S	T^S	T^S	T^S		
	FEB								
	MAR	T^F	T^F	T^S	T^S	N^S	T^F		
	APR	T^F	T^F	T^F	T^S	D^B	T^F		
	MAY	T^F	T^F	T^F	T^S	D^S	T^F		
	JUN	D^S	D^S	D/N^B	D^B	T^F	T^F		
	JUL	D	D/N^S	D/N^B	D^B	T^F	T^F		
	AUG								
	SEP								
	OCT	N^S	D/N^E	D/N^B	D/N^S	T^F	T^F		
	NOV	N	D^S	D/N^B	D/N^B	T^F	T^F		
	DEC	N	N^B	N^B	N^B	T^F	T^F		
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND. J - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE B-18

FIXED MONITOR: PORTSMOUTH, VA, U.S.A. FREQUENCY: 10.2 kHz 5620

YR.	MO.	LOP AB	AC	AD	CD	DF	DH		
1978	JAN	T^F	T^F	T^F	T^F	T^F	T^F		
	FEB	T^F	T^F	T^F	T^F	T^F	T^F		
	MAR								
	APR	T^F	T^F	T^F	D/N	D/N^S	T^F		
	MAY	T^F	T^F	T^F	D/N^S	D^S	T^F		
	JUN								
	JUL								
	AUG	T^F	T^F	T^F	D^S	T^S	T^S		
	SEP	T^B	D^S	D/N^S	D/N	D/N^S	T^S		
	OCT	D/N^B	T	D/N	D/N	D/N^S	T^S		
	NOV	N^B	T	N	D/N	D/N^B	T^S		
	DEC	D/N^B	D/N	D/N	D/N	D/N^S	D/N		
1979	JAN								
	FEB	D^B	T^S	T^S	D/N^S	D/N^B	T^S		
	MAR	T^F	T^F	T^F	D/N	D/N^S	T		
	APR	T^F	T^F	T^F	D/N	D/N^S	T^F		
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

5620

TABLE B-19

FIXED MONITOR: RESOLUTE, NWT, CANADA

FREQUENCY: 10.2 kHz

YR.	MO.	LOP							
		AC							
1971	JAN	T							
	FEB	T							
	MAR	T							
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV	T							
	DEC	N							
1972	JAN	T							
	FEB	T							
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND. [illegible] - Day & Night; D - No Nighttime;
N [illegible]o Daytime; T - Transition Only;
Flags S, Q, B, E, F - See accompanying description

TABLE B-20

6620

FIXED MONITOR: SABANA SECA, PUERTO RICO FREQUENCY: 10.2 kHz

YR.	MO.	LOP AC	AD	CD	BD	AF	DF		
1975	JAN								
	FEB								
	MAR								
	APR								
	MAY	D		D/N					
	JUN	D^{B}	D	D/N					
	JUL	D^{B}	D	D/N^{B}					
	AUG	D	D	D/N					
	SEP	T							
	OCT	T	D/N	D/N					
	NOV	T	N	D/N					
	DEC	N^{B}	N	D/N^{B}					
1976	JAN	T^{B}	N	D/N^{B}					
	FEB	T^{B}	N	D/N^{B}	D/N^{B}				
	MAR	T^{B}	N	D/N^{B}	D/N^{B}				
	APR	D^{B}	D	D/N^{B}	D/N^{B}				
	MAY	D^{B}		D/N					
	JUN	D^{B}		D/N		D^{B}	D/N^{B}		
	JUL	D		D/N		D^{B}	D/N^{B}		
	AUG	D		D/N^{B}		D^{S}	D/N^{B}		
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP AC	AD	CD	BD	AF	DF	CF	CH
1977	JAN	T^{B}		D/N^{B}		N^{B}			
	FEB	T^{B}		D/N^{B}		D/N^{B}	D/N^{B}		
	MAR								
	APR	D^{B}		D/N^{B}		D^{S}	D/N^{S}		
	MAY	D		D/N		D^{B}	D/N^{B}		
	JUN	D		D/N		D^{B}	D/N^{B}		
	JUL								
	AUG								
	SEP	T^{B}		D/N		D^{S}	D/N^{B}		
	OCT	T^{B}		D/N		D/N^{E}	D/N^{B}		
	NOV								
	DEC	N^{B}	N	D/N^{B}	D/N^{B}	T^{S}	D/N^{B}	D/N^{B}	T^{F}
1978	JAN								
	FEB	T^{S}		D/N^{B}		T^{S}	D/N^{S}		
	MAR			D/N^{B}		T^{F}	T^{F}		
	APR								
	MAY		T^{F}	D/N	D/N^{B}			D^{B}	T^{F}
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE B-21

5620

FIXED MONITOR: SARDINIA, ITALY

FREQUENCY: 10.2 kHz

YR.	MO.	LOP: AB	AD						
1973	JAN								
	FEB								
	MAR		D/N^B						
	APR								
	MAY		D^B						
	JUN		D^B						
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC		N^B						
1974	JAN		N^B						
	FEB		N^B						
	MAR		N^B						
	APR		D^B						
	MAY		D^B						
	JUN		D^B						
	JUL		D^B						
	AUG		D^B						
	SEP								
	OCT		D/N^B						
	NOV		N^B						
	DEC								

YR.	MO.	LOP: AB	AD	AE	AF	BD	BH		
1975	JAN		N^B						
	FEB		N^B						
	MAR		D/N^B						
	APR		D^B						
	MAY		D^B						
	JUN		T^B						
	JUL		T^S						
	AUG								
	SEP								
	OCT								
	NOV								
	DEC		N^B						
1978	JAN								
	FEB								
	MAR	D/N^B	N	N^B	T^F	N^B	T^B		
	APR	T^F							
	MAY	T^S	T^S	T^S	T^F	D^S	D^S		
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND 'N - Day & Night; D - No Nighttime;
- No Daytime; T - Transition Only;
Flags S, Q, B, E, F - See accompanying description

TABLE B-22

6620

XED MONITOR: ST. ANTHONY, NEWFOUNDLAND   FREQUENCY: 10.2 kHz

YR.	MO.	LOP: AC							
1968	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC	N							
1969	JAN	T							
	FEB	T							
	MAR	T							
	APR	D							
	MAY	D							
	JUN	D							
	JUL								
	AUG	D							
	SEP	T							
	OCT	T							
	NOV	T							
	DEC	N							

YR.	MO.	LOP: AC	AB	AD	CD	CF	EF		
1970	JAN	T							
	FEB	T							
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
1977	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC	N	N^{S}	N	N	T^{B}	T^{S}		

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, Q, B, E, F - See accompanying description

TABLE B-23

5620

FIXED MONITOR: TASC, READING, MA., U.S.A.   FREQUENCY: 10.2 kHz

YR.	MO.	LOP							
		AD	CD						
1974	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT	D/N							
	NOV	N	D/N						
	DEC	N	D/N						
1975	JAN		D/N						
	FEB	N	D/N						
	MAR	D/N	D/N						
	APR		D/N						
	MAY		D/N						
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND 'N - Day & Night; D - No Nighttime;
. - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLF B-24

5620

FIXED MONITOR: VILANOVA, AZORES

FREQUENCY: 10.2 kHz

YR.	MO.	LOP AD	LOP AH	LOP AB	LOP BD	LOP AF	LOP DF		
1975	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT	D/N							
	NOV	N	T^B						
	DEC	N^B	N^B						
1976	JAN	N^B	N^B						
	FEB	N^B	T^B	D/N	D/N				
	MAR	N^B	D/N^B	N^S					
	APR	D	T^B	D/N	D/N				
	MAY		D^S	D	D/N				
	JUN			D	D/N	D/N^B	D/N^E		
	JUL			D	D/N	D/N^B	D/N^B		
	AUG			D/N	D/N	D/N^B	D/N^B		
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP AD	LOP AH	LOP AB	LOP BD	LOP AF	LOP DF		
1977	JAN								
	FEB								
	MAR								
	APR			D/N^S	D/N	D/N^B	D/N^B		
	MAY								
	JUN								
	JUL								
	AUG			D/N	D/N	D/N^B	D/N^B		
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE B-25

5620

FIXED MONITOR: WASHINGTON, D.C., U.S.A.

FREQUENCY: 10.2 kHz

YR.	MO.	LOP AB	AC	AD	CD	DF	DH		
1978	JAN	T^F	T^F	T^F	D/N	D/N^S	T^F		
	FEB								
	MAR	T^F	T^F	T^F	T^F	T^F	T^F		
	APR								
	MAY								
	JUN	D^S	D	D	D/N	D/N^S	D^E		
	JUL	D^S	T	D	D/N	D/N^B	D^B		
	AUG	D^B	T	D	D/N	D/N^S	D^E		
	SEP	D/N^B	T	D	D/N	D/N^S	T^E		
	OCT								
	NOV	N^B	T	N	D/N	D/N^S	T^B		
	DEC								
1979	JAN	N^B	T^S	N	D/N	D/N^S	T^S		
	FEB	D/N^B	T	N	D/N	D^B	T^B		
	MAR	N^S	T^F	T^F	D/N	D/N^S	T^F		
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags S, O, B, E, F - See accompanying description

TABLE B-26

5620

FIXED MONITOR: Yorktown, VA., U.S.A. FREQUENCY: 10.2 kHz

YR.	MO.	LOP							
		CD							
1976	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN	D/N							
	JUL	D/N							
	AUG	D/N							
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

YR.	MO.	LOP							
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								
19	JAN								
	FEB								
	MAR								
	APR								
	MAY								
	JUN								
	JUL								
	AUG								
	SEP								
	OCT								
	NOV								
	DEC								

LEGEND: D/N - Day & Night; D - No Nighttime;
N - No Daytime; T - Transition Only;
Flags: S, Q, B, E, F - See accompanying description

APPENDIX C

Individual Coverage Maps

Included in this Appendix are individual maps showing values of 10.2 kHz SNR and coverage contours as follows:

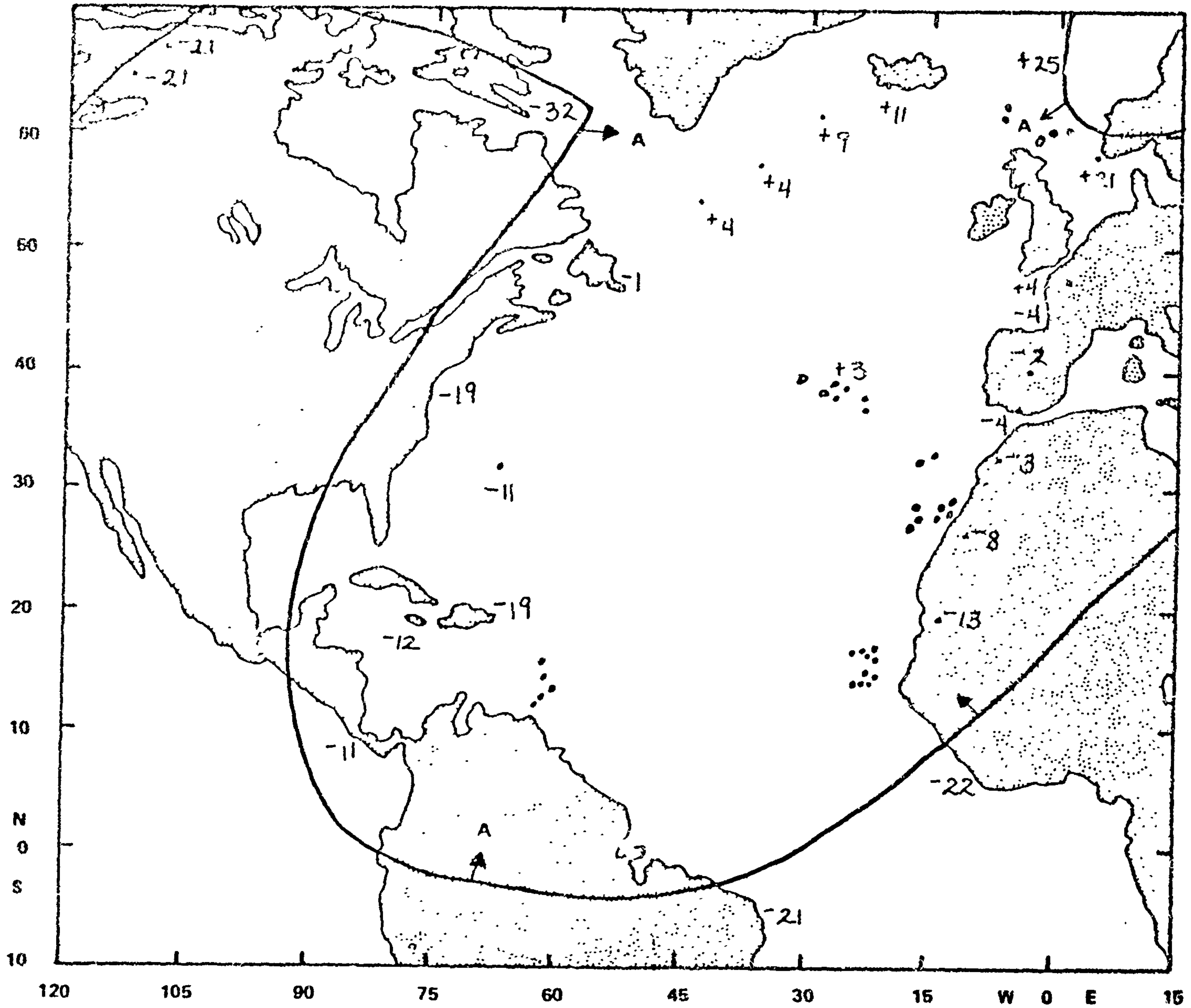

Figure C-1 OMEGA Static Coverage - Summer Day

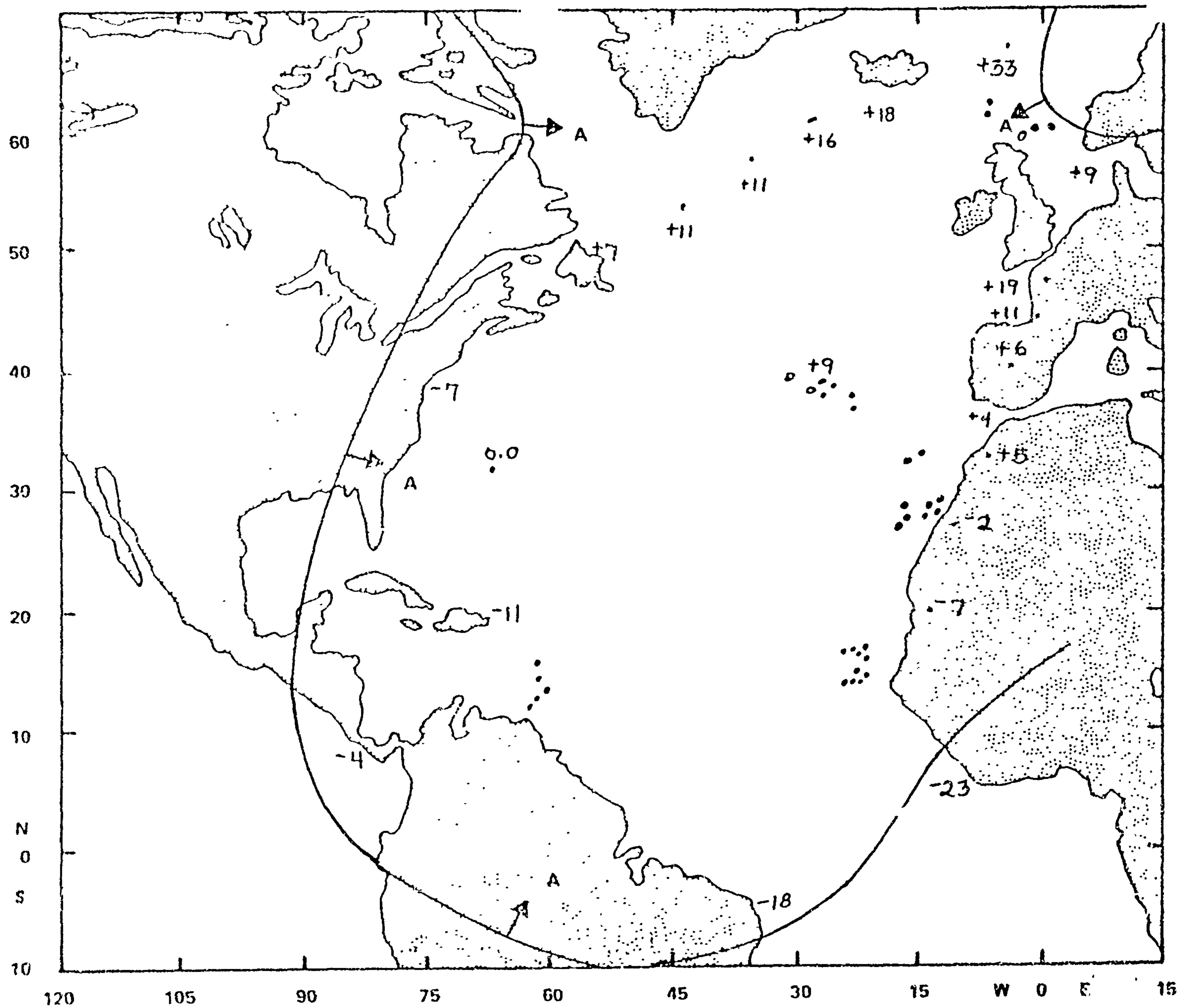

Figure C-3 OMEGA Station A Coverage - Winter Day

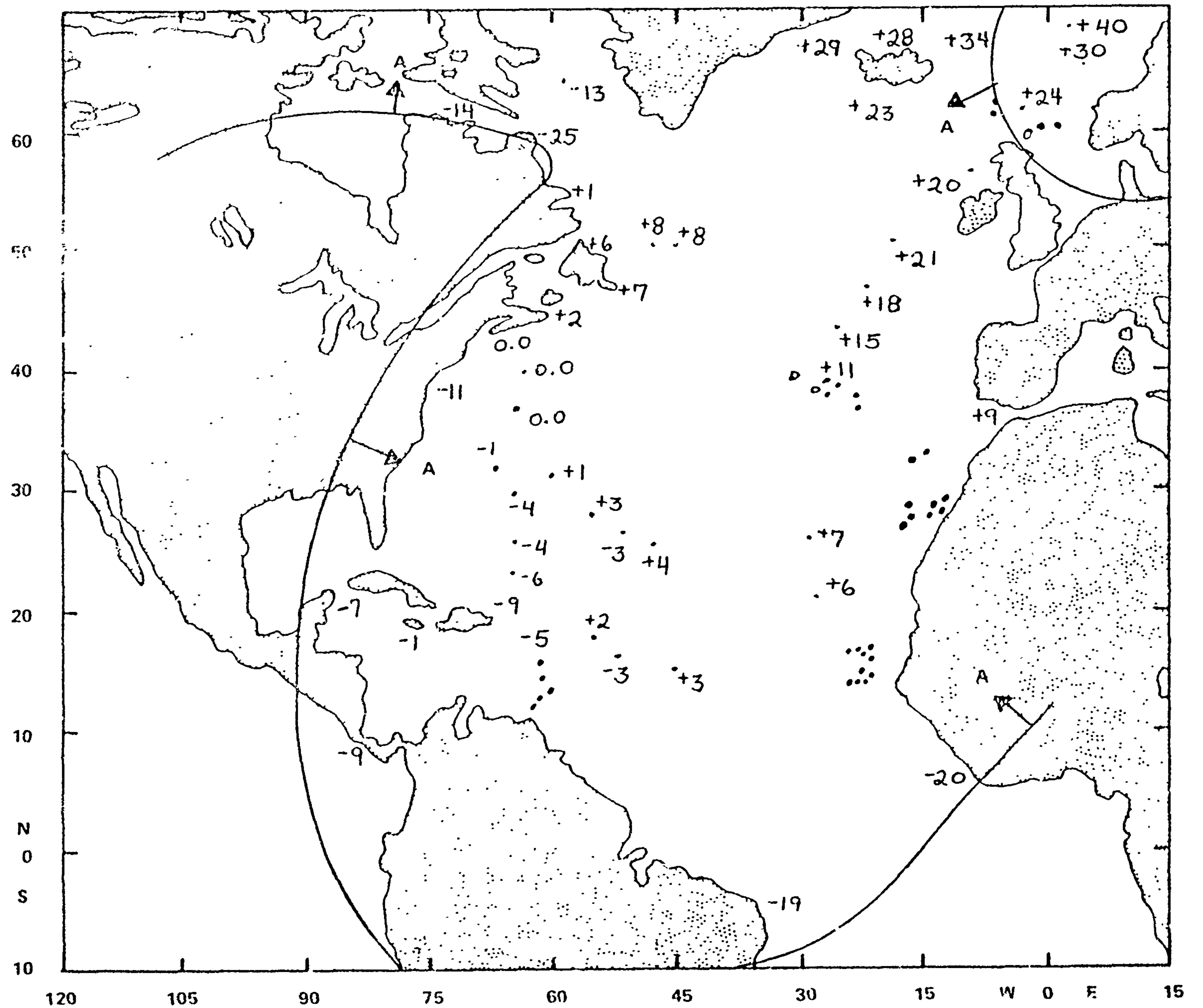

Figure C-2 OMEGA Station A Coverage - Summer Night

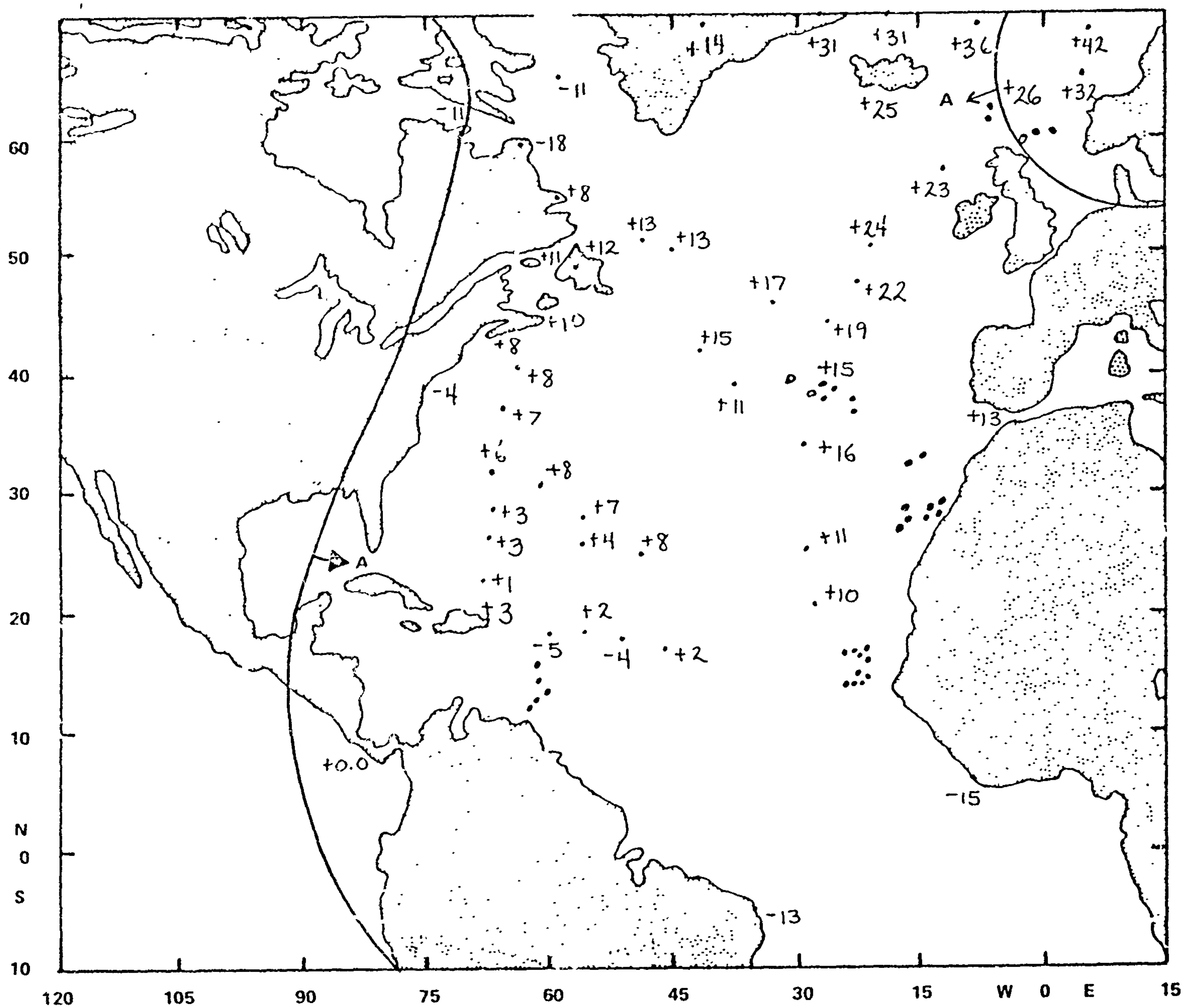

Figure C-4 OMEGA Station A Coverage - Winter Night

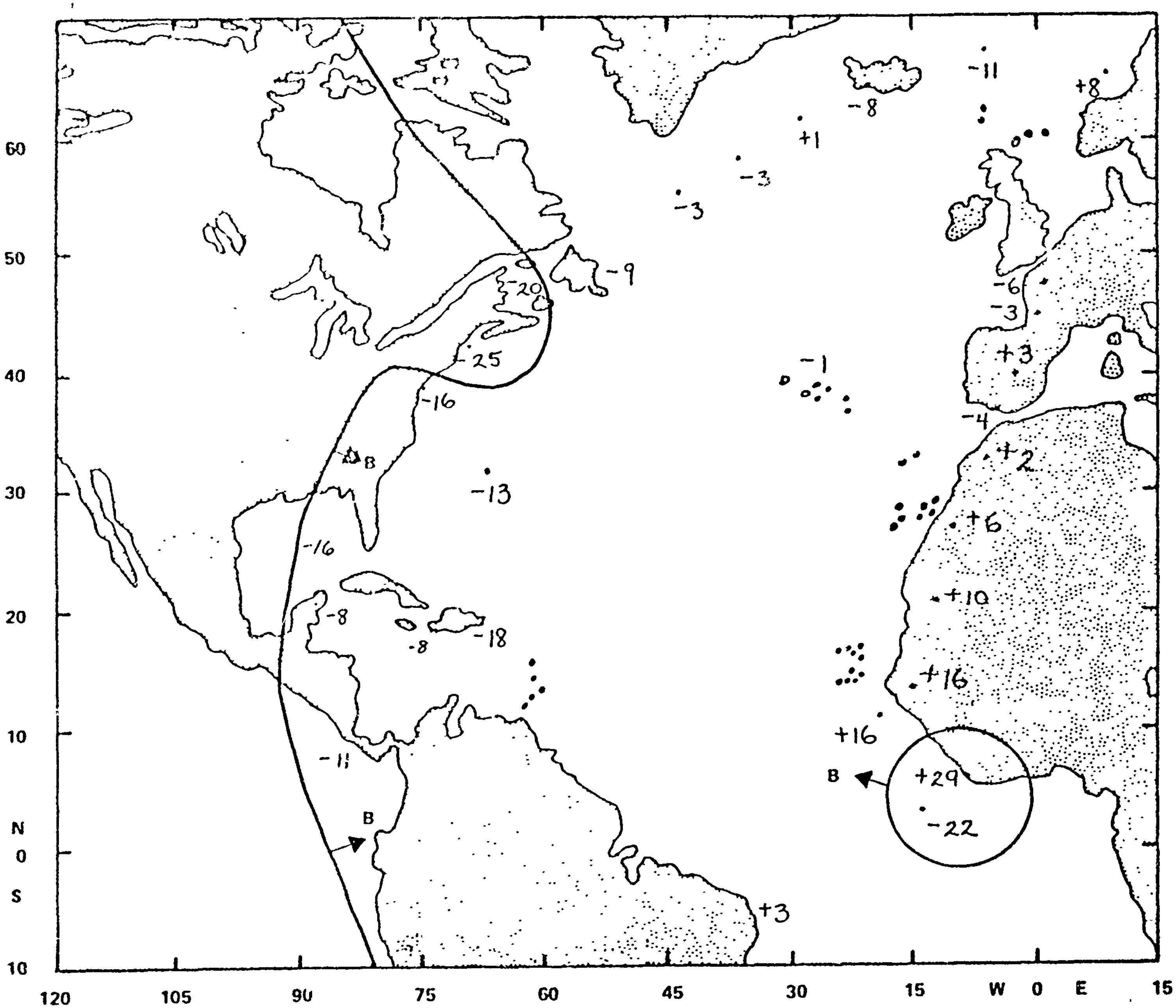

Figure C-5 OMEGA S ion B Coverage - Summer Day

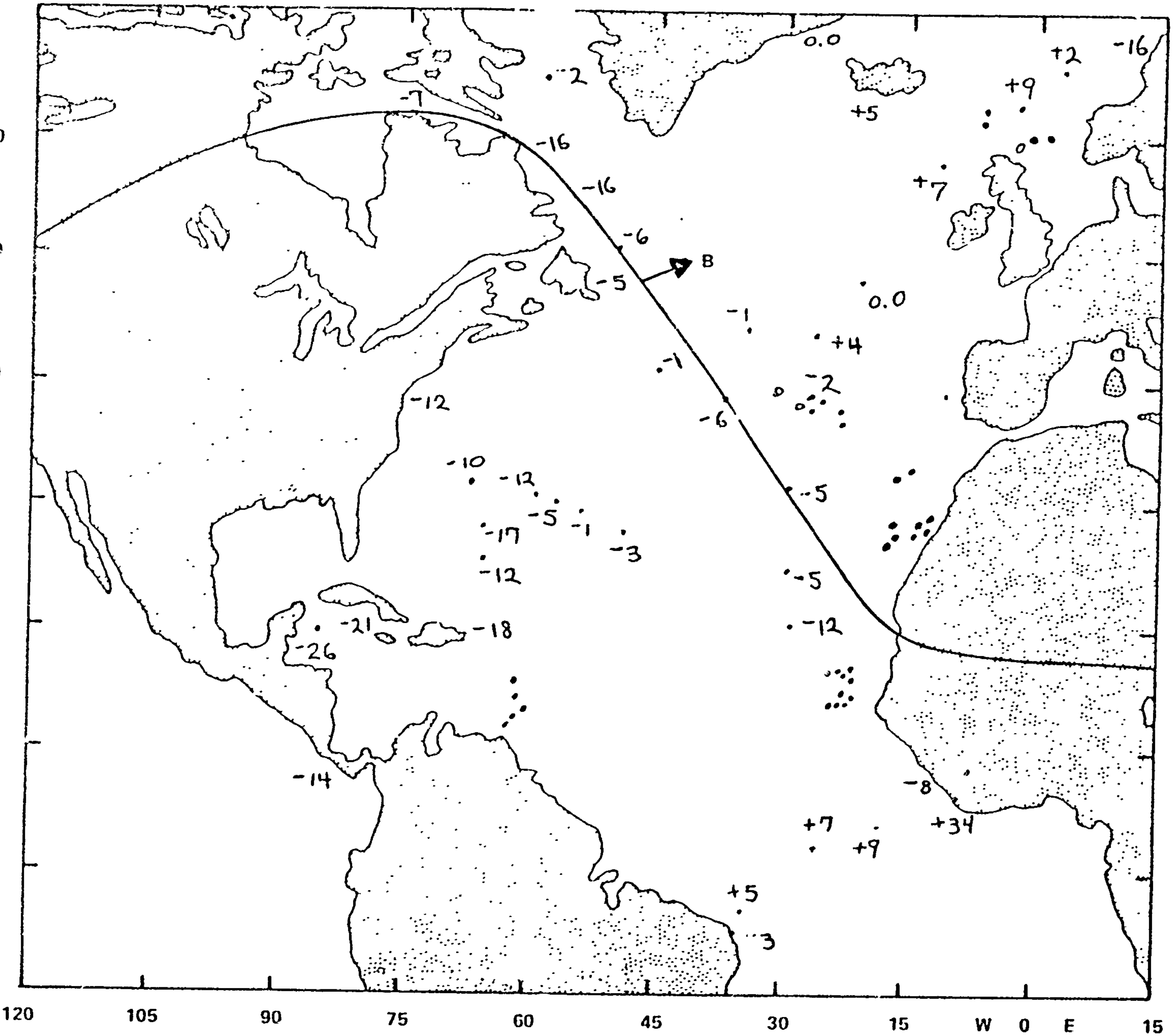

Figure C-6 OMEGA Station B Coverage - Summer Night

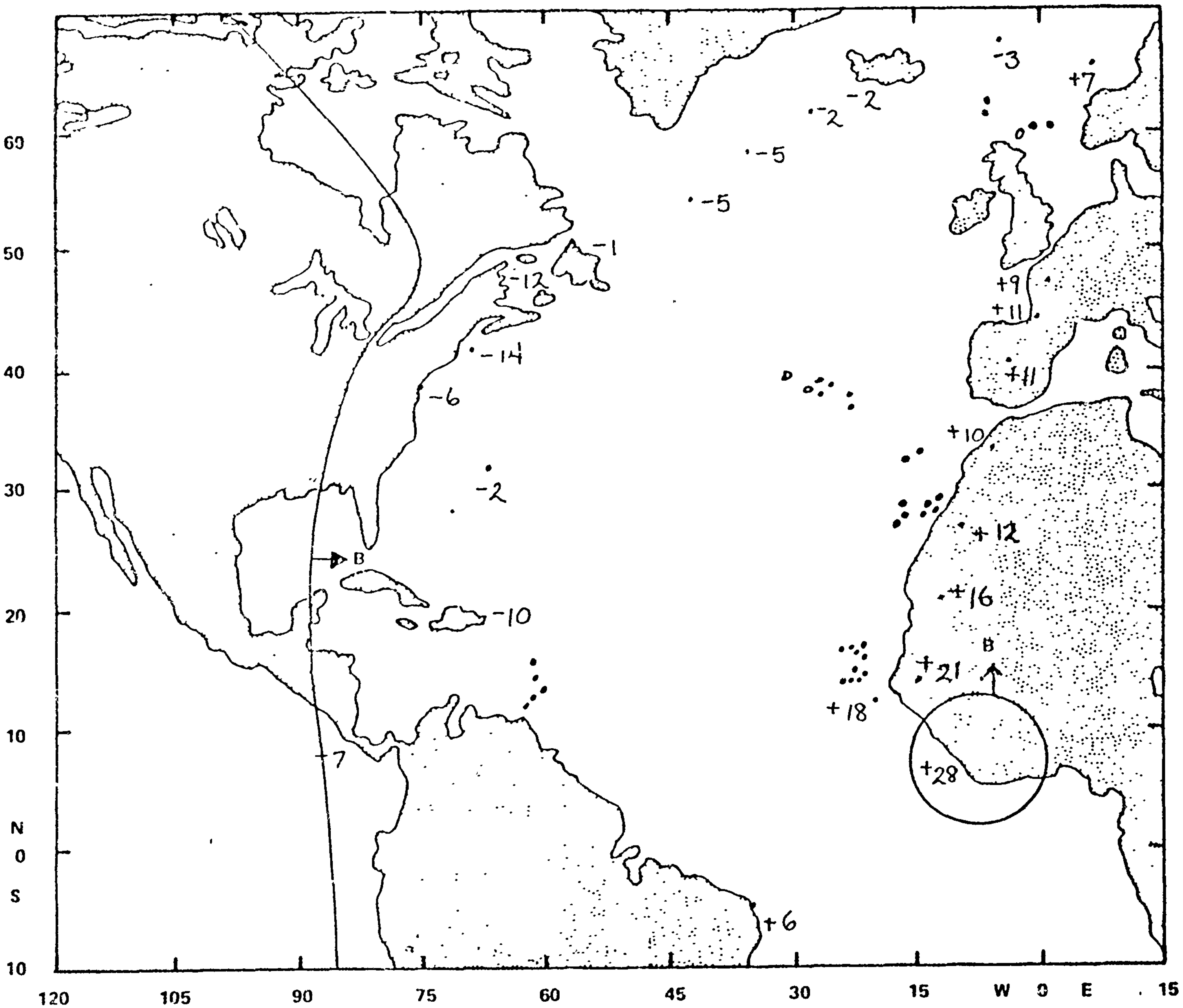

Figure C-7 OMEGA Station B Coverage - Winter Day

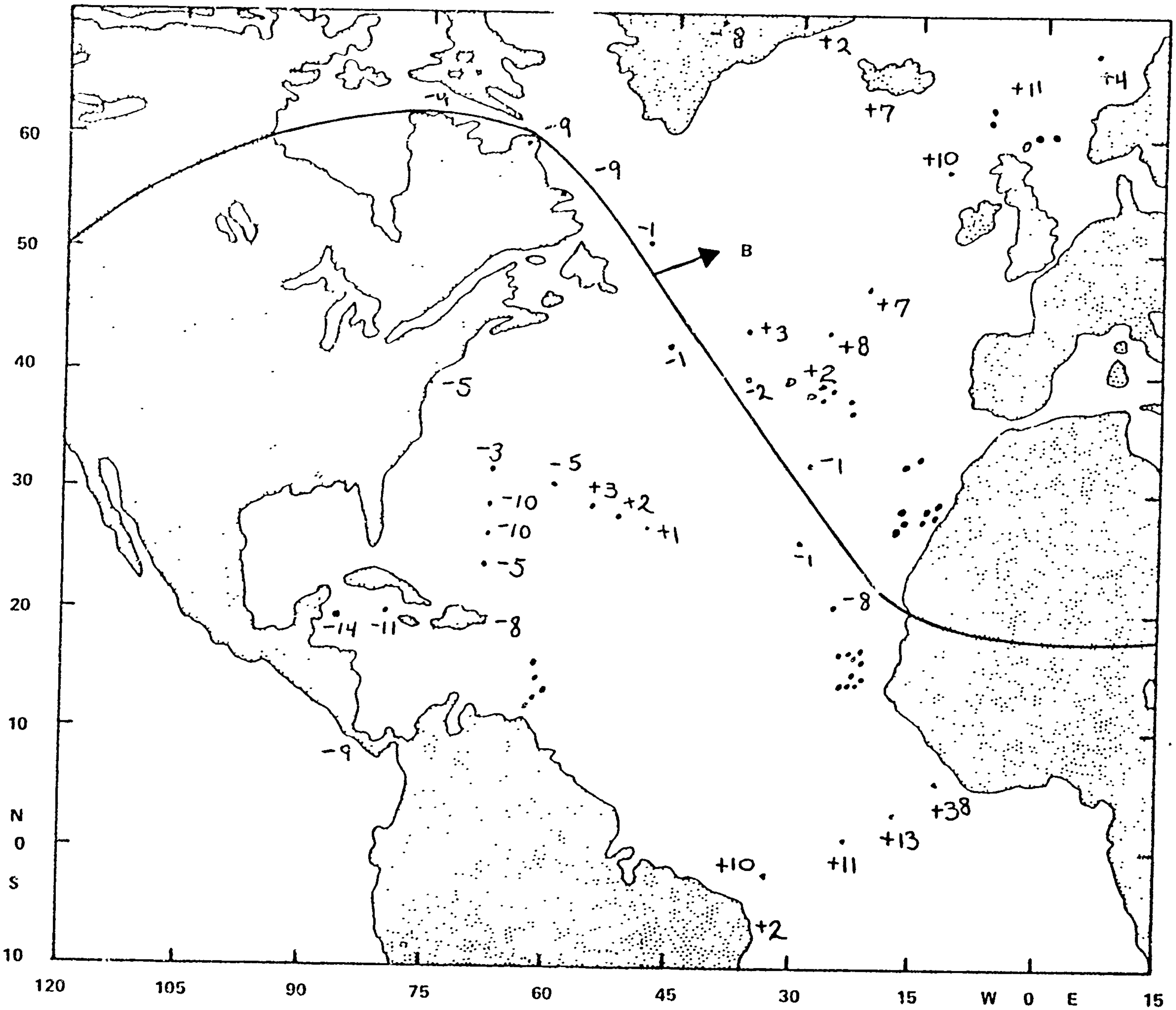

Figure C-8 OMEGA Station B Coverage - Winter Night

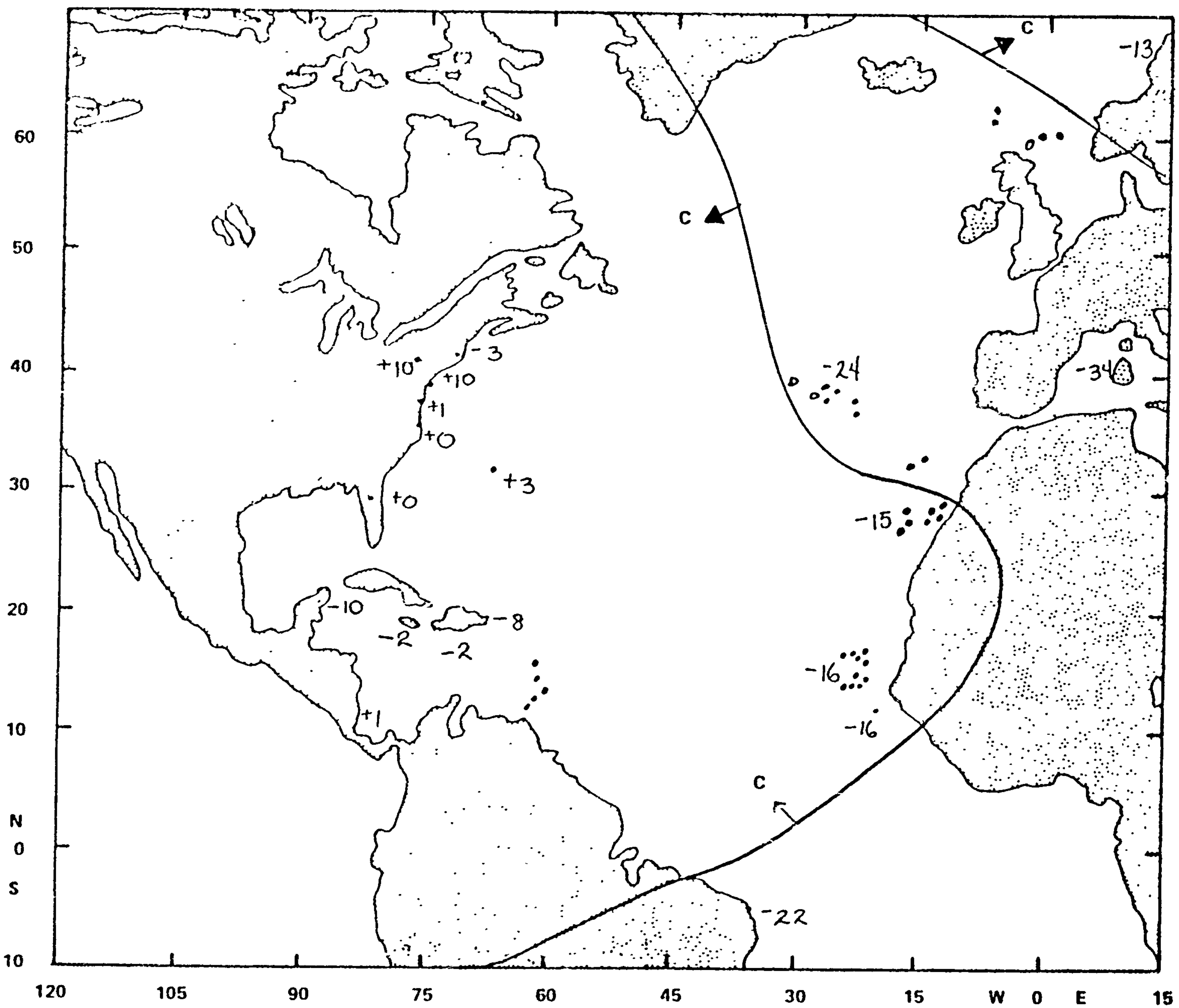

Figure C-9 OMEGA St· ɔn C Coverage - Summer Day

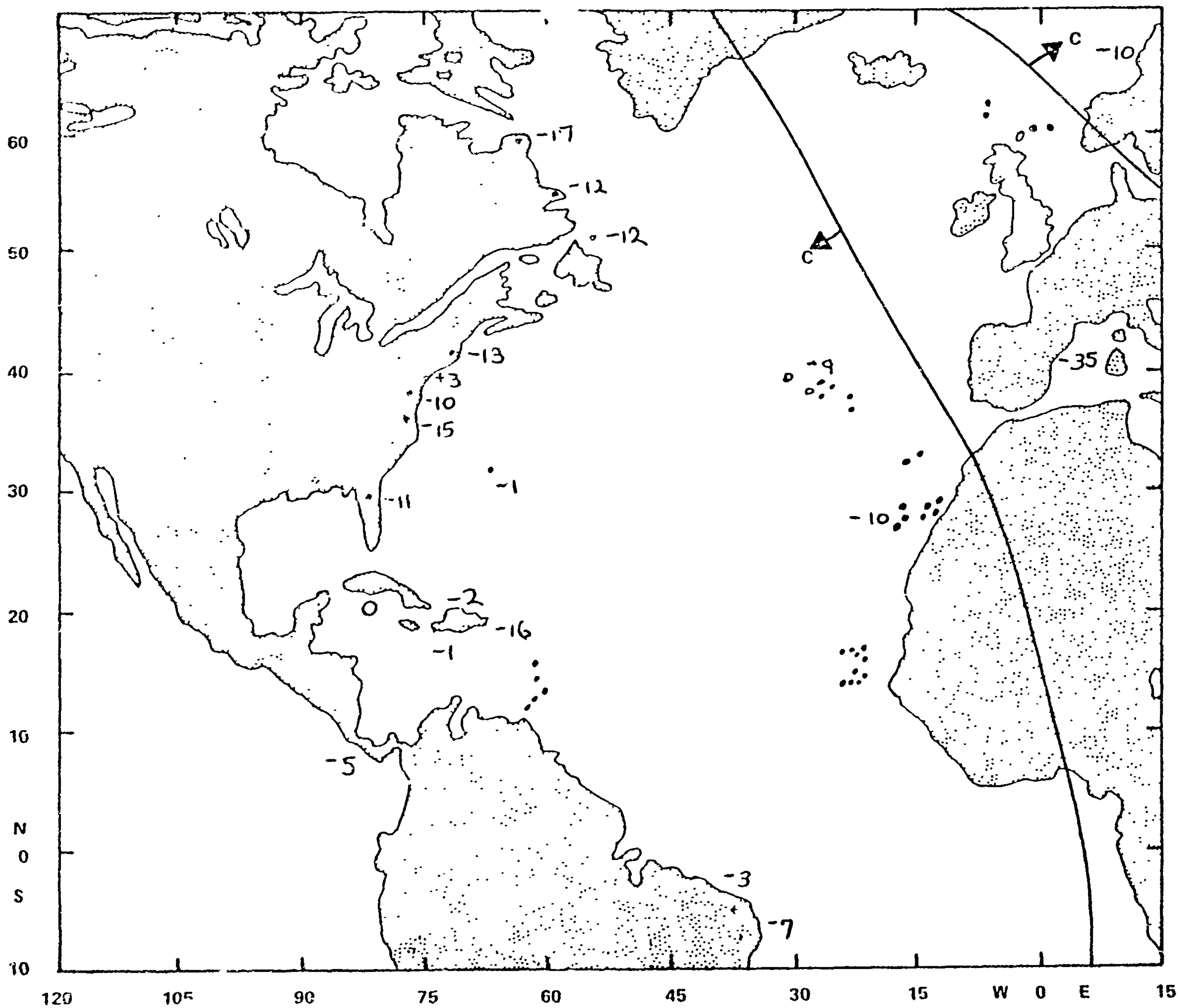

Figure C-10 OMEGA Station C Coverage - Summer Night

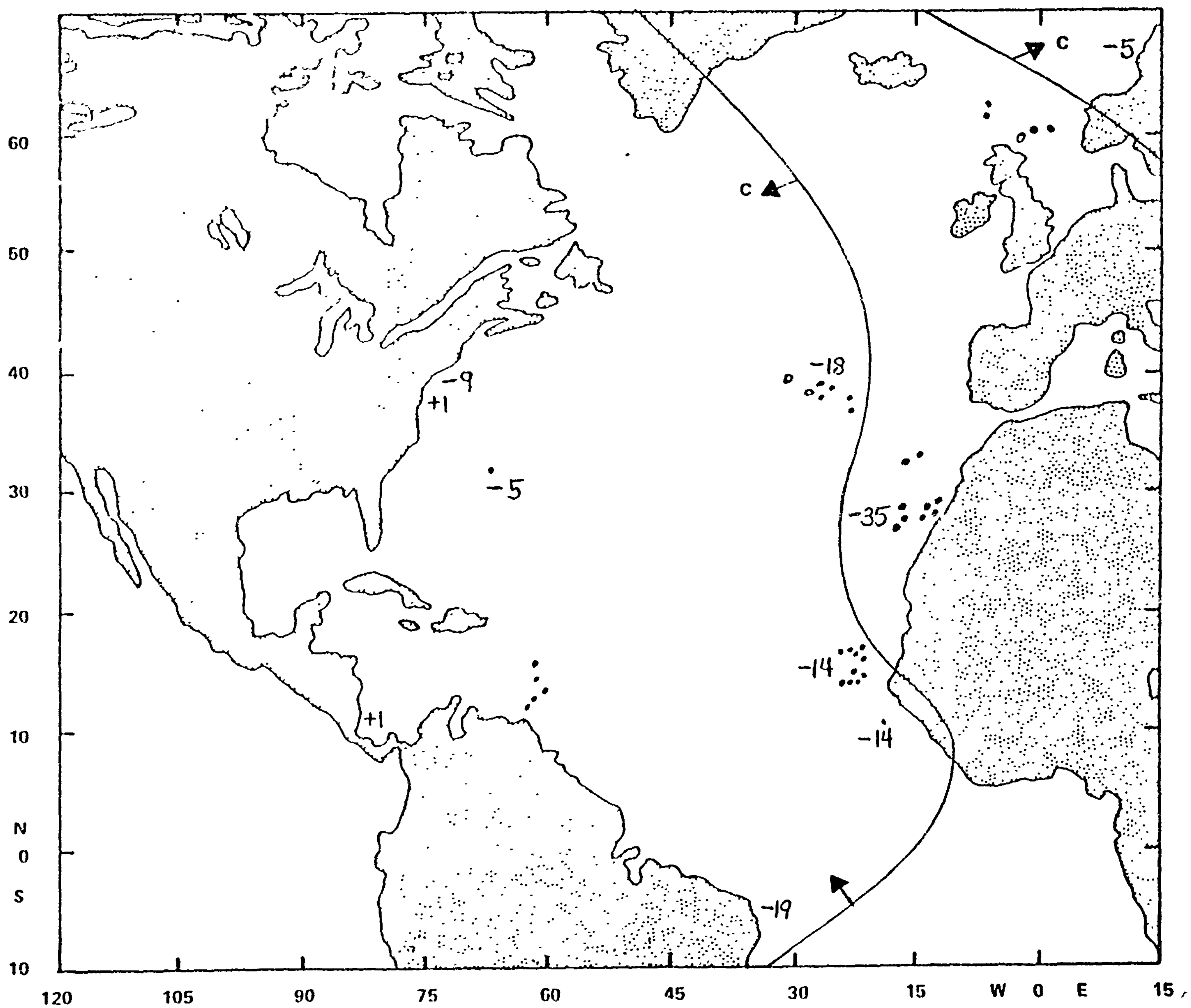

Figure C-11 OMEGA Station C Coverage - Winter Day

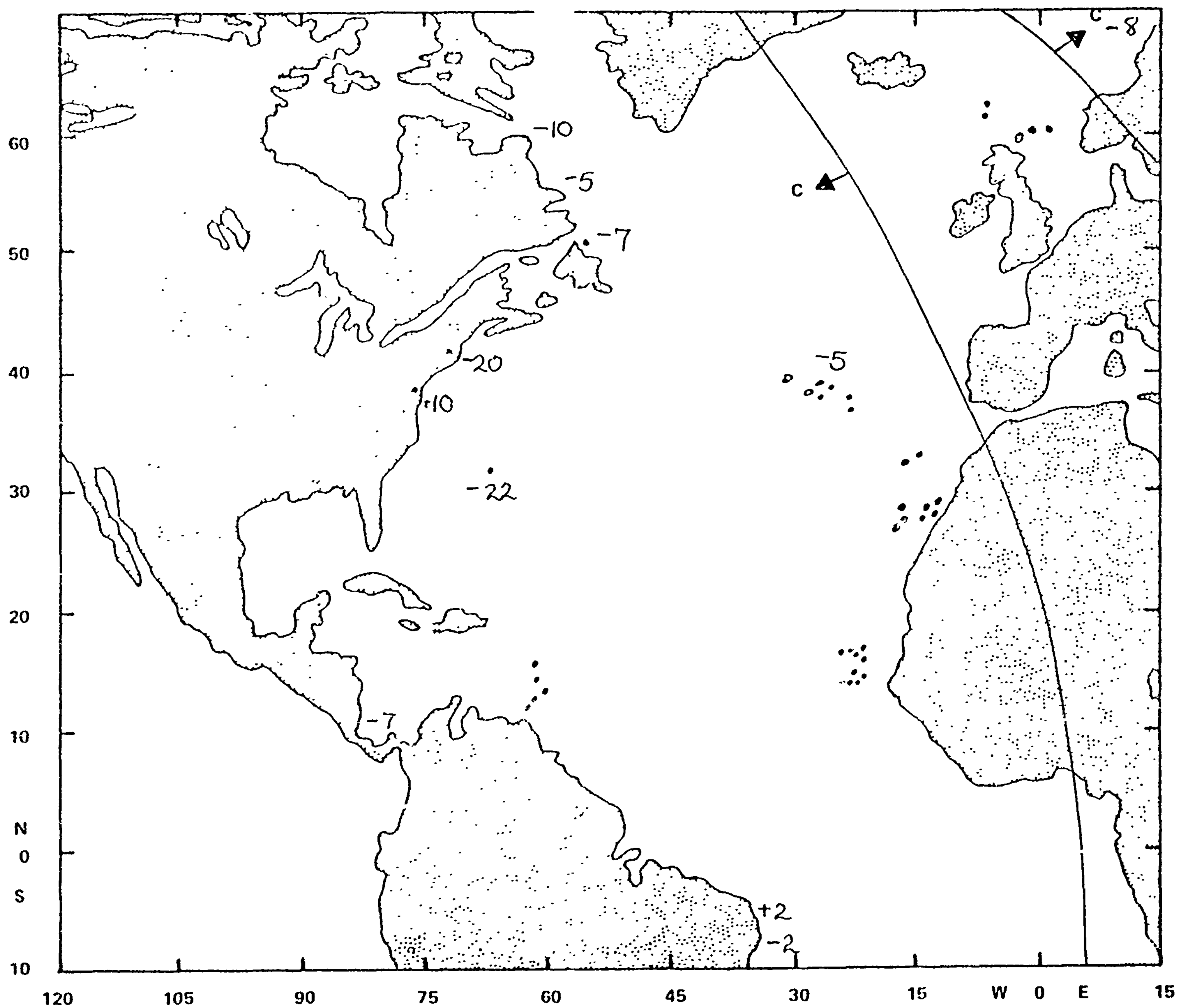

Figure C-12 OMEGA Station C Coverage - Winter Night

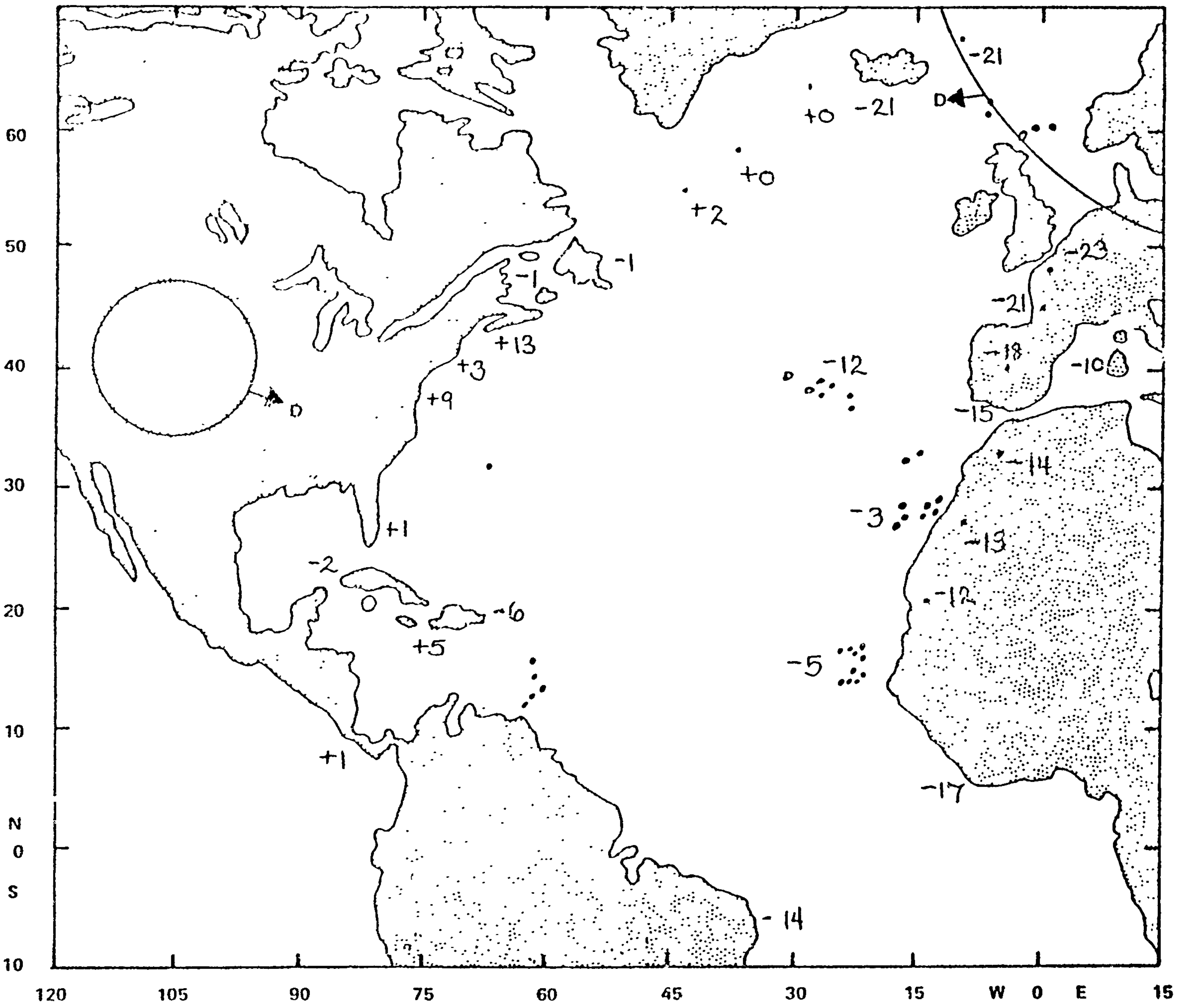

Figure C-13 OMEGA Station D Coverage - Summer Day

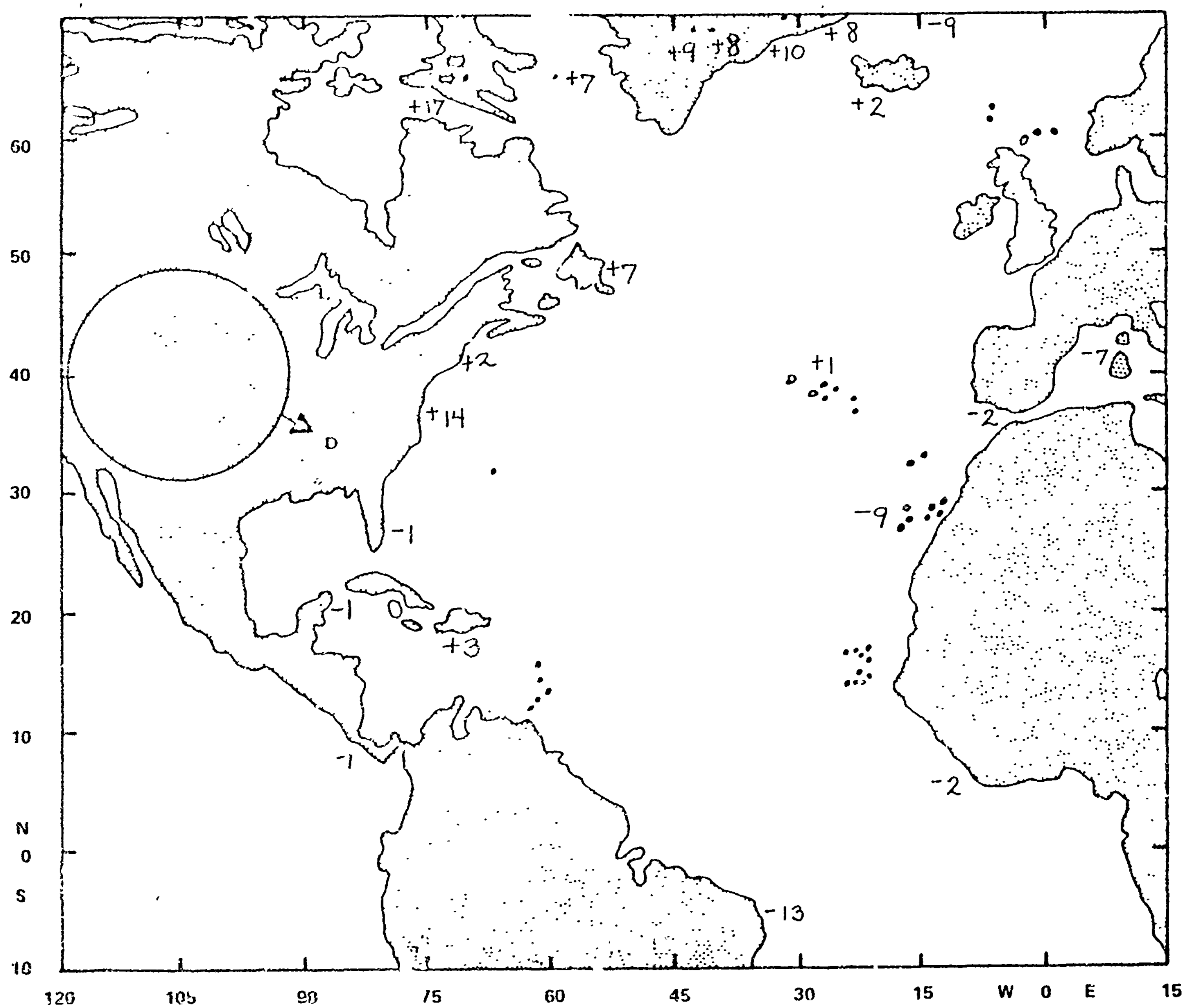

Figure C-14 OMEGA Station D Coverage - Summer Night

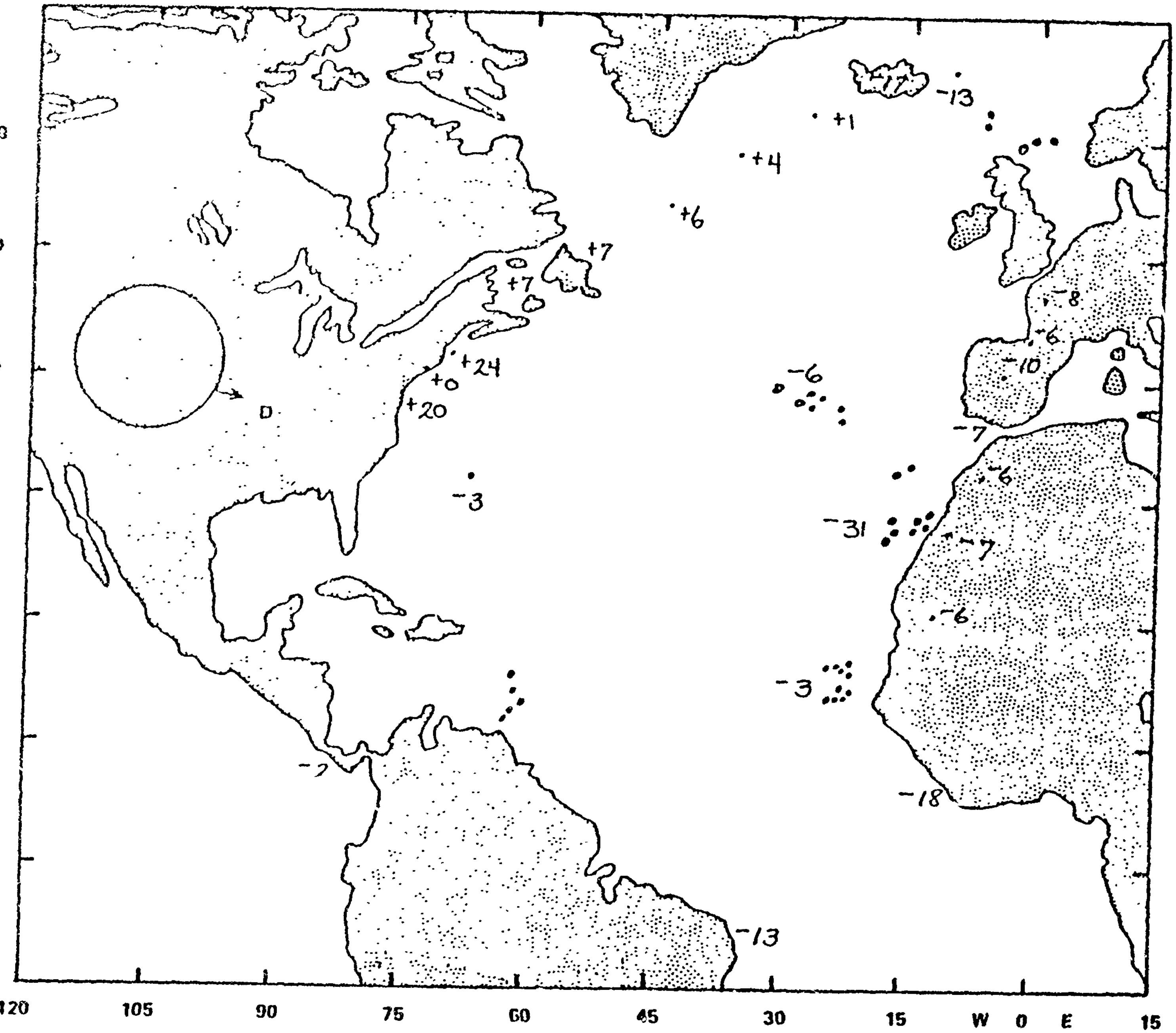

Figure C-15 OMEGA Sta' 'n D Coverage - Winter Day

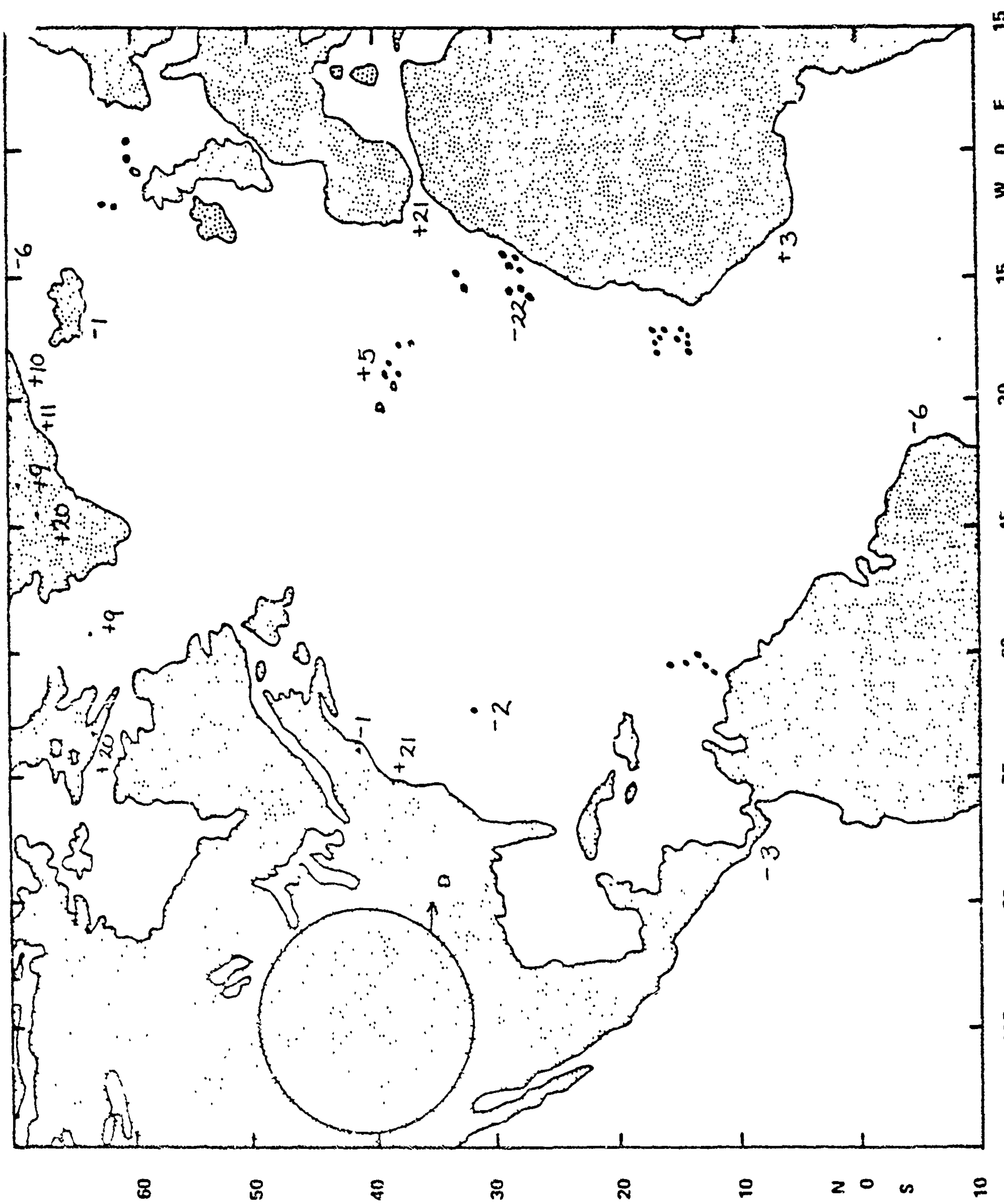

Figure C-16 OMEGA Station D Coverage - Winter Night

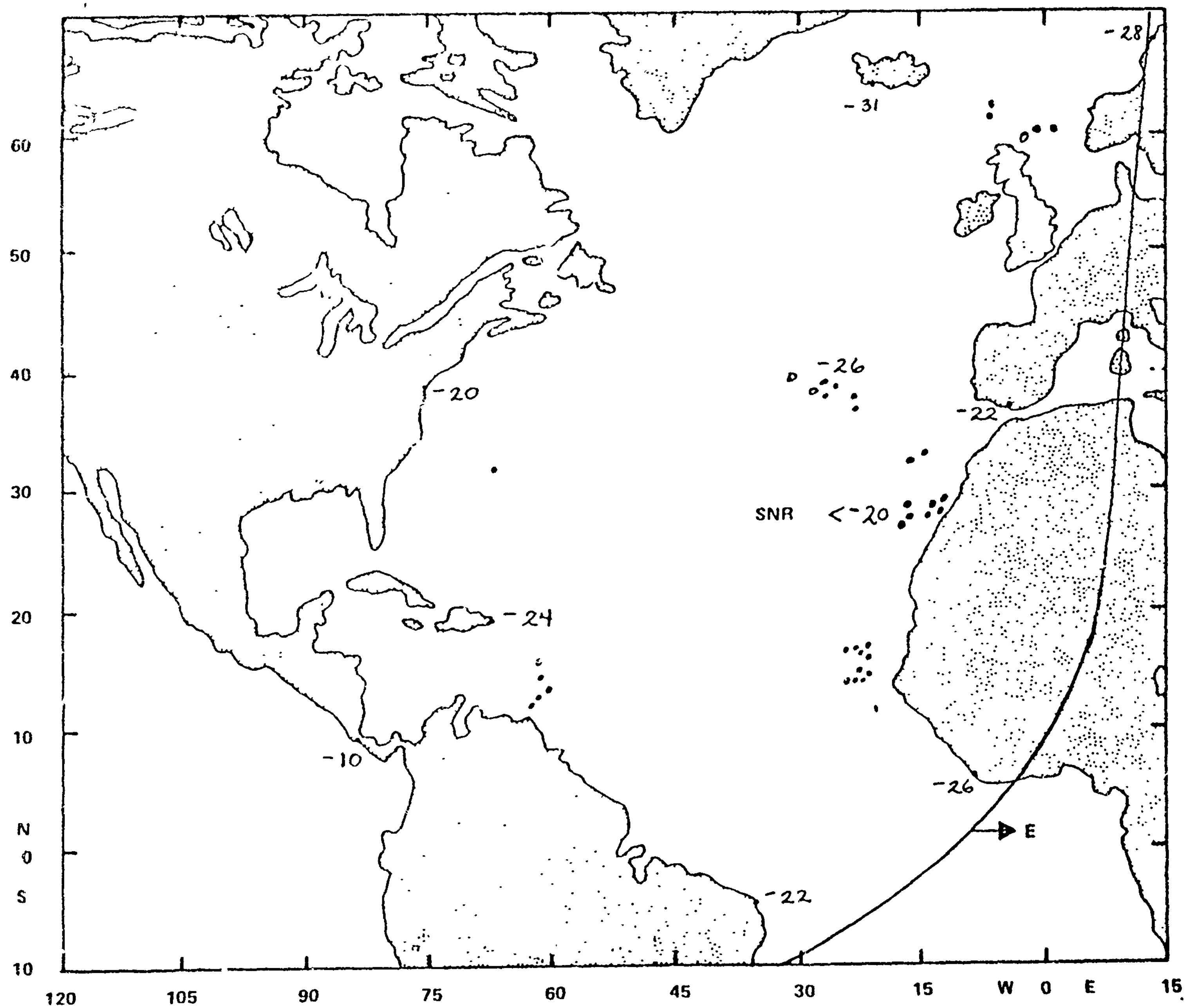

Figure C-17 OMEGA Station E Coverage - Summer Day

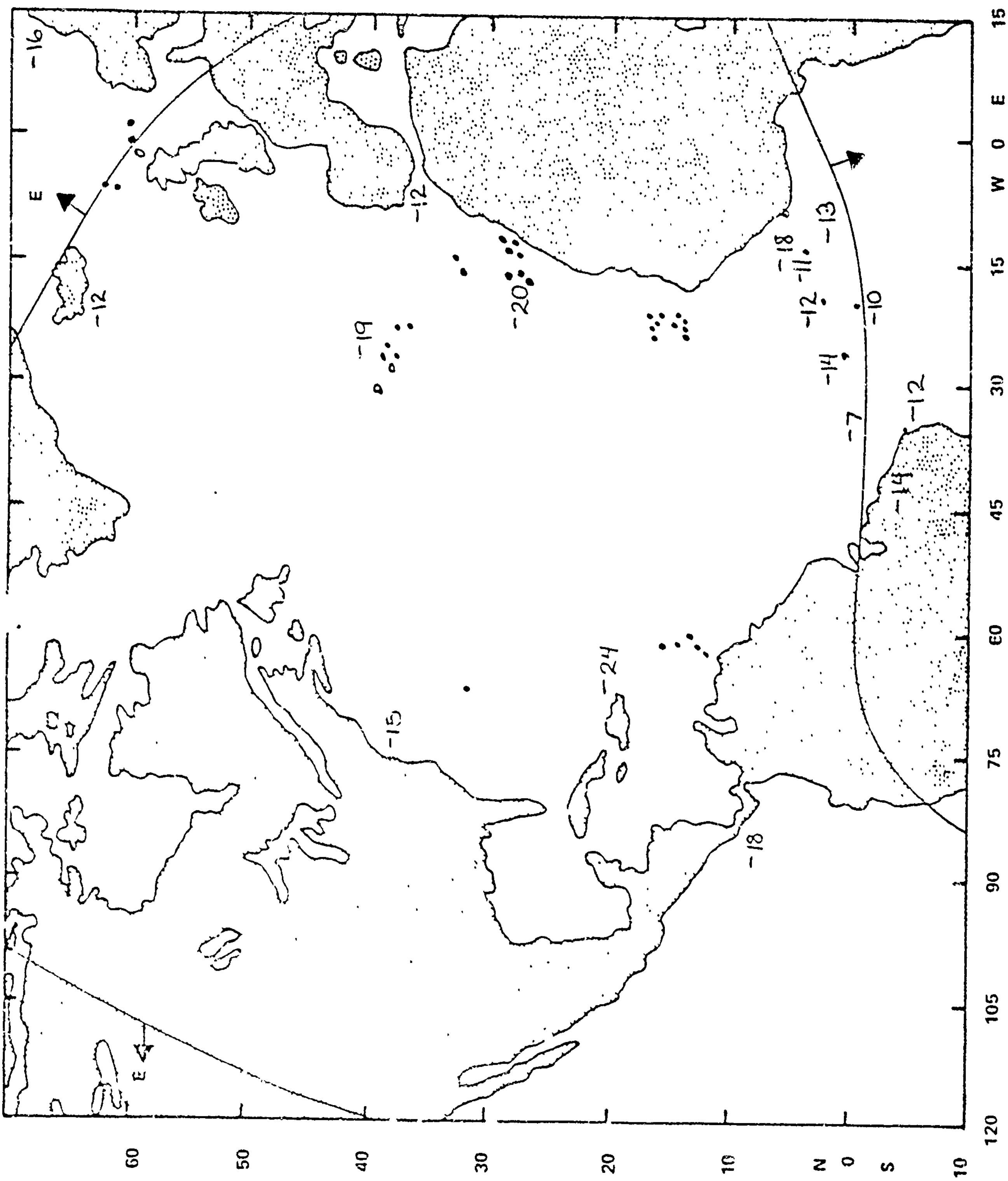

Figure C-18 OMEGA Station E Coverage - Summer Night

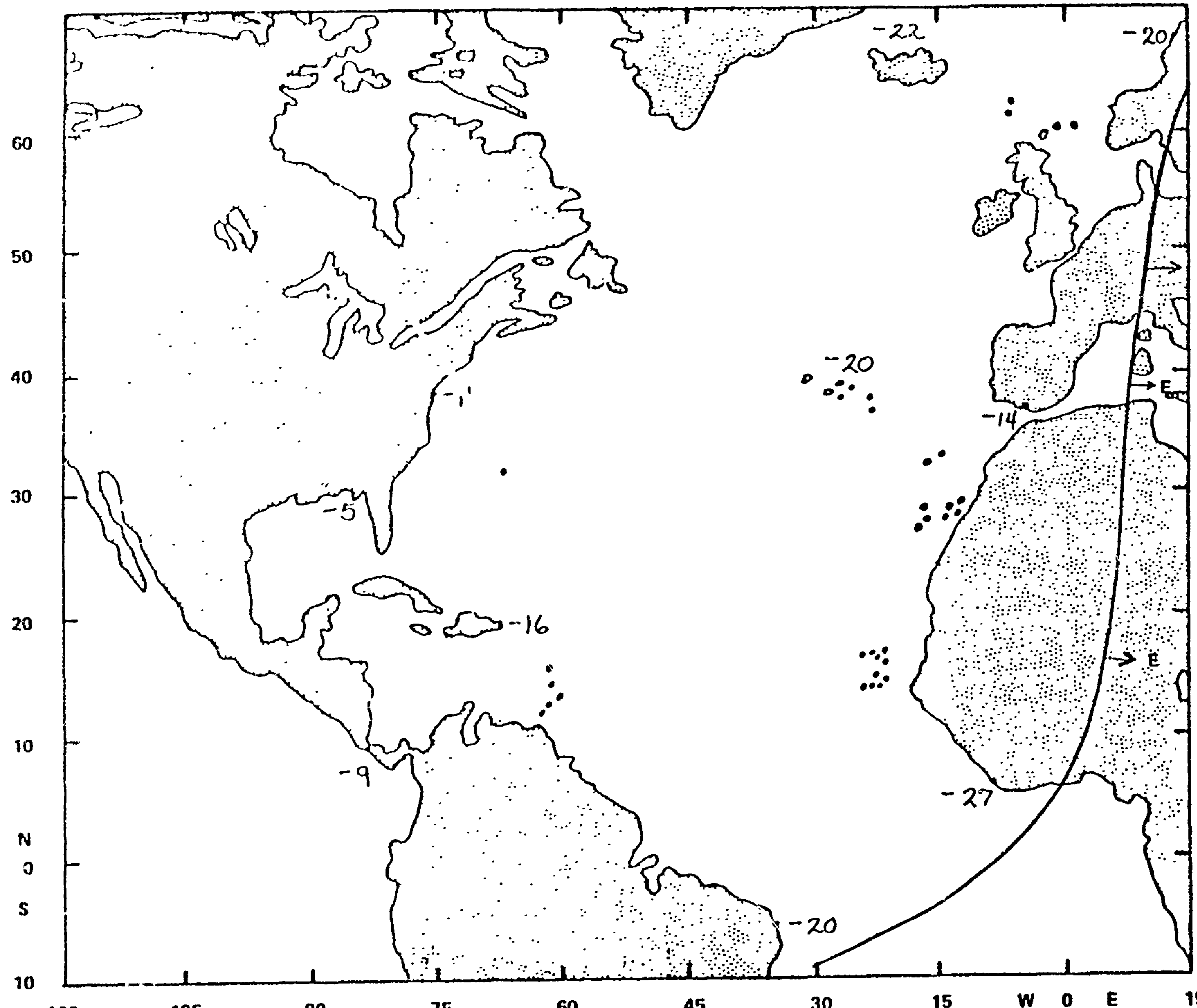

Figure C-19 OMEGA Station E Coverage - Winter Day

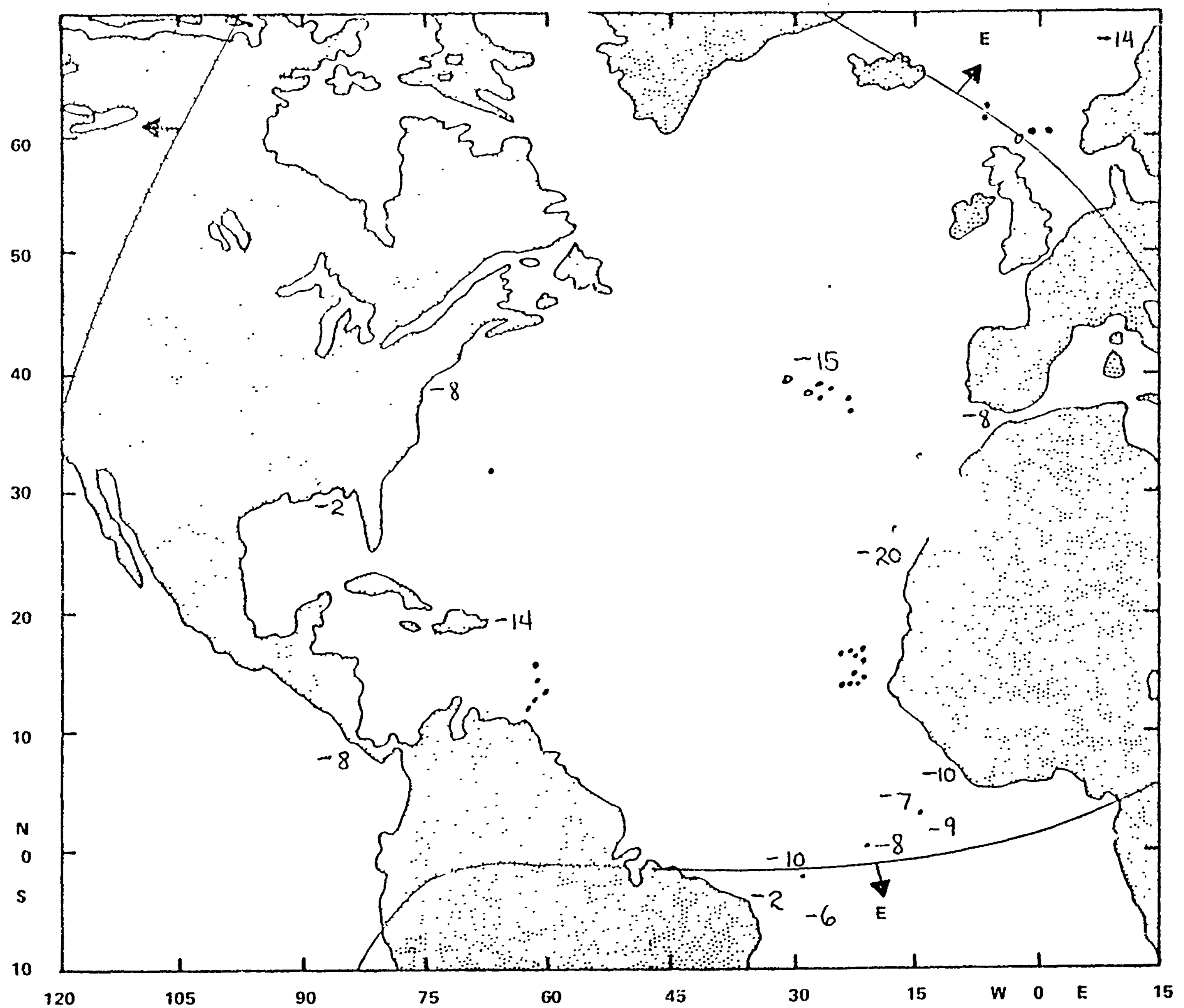

Figure C-20 OMEGA Station E Coverage - Winter Night

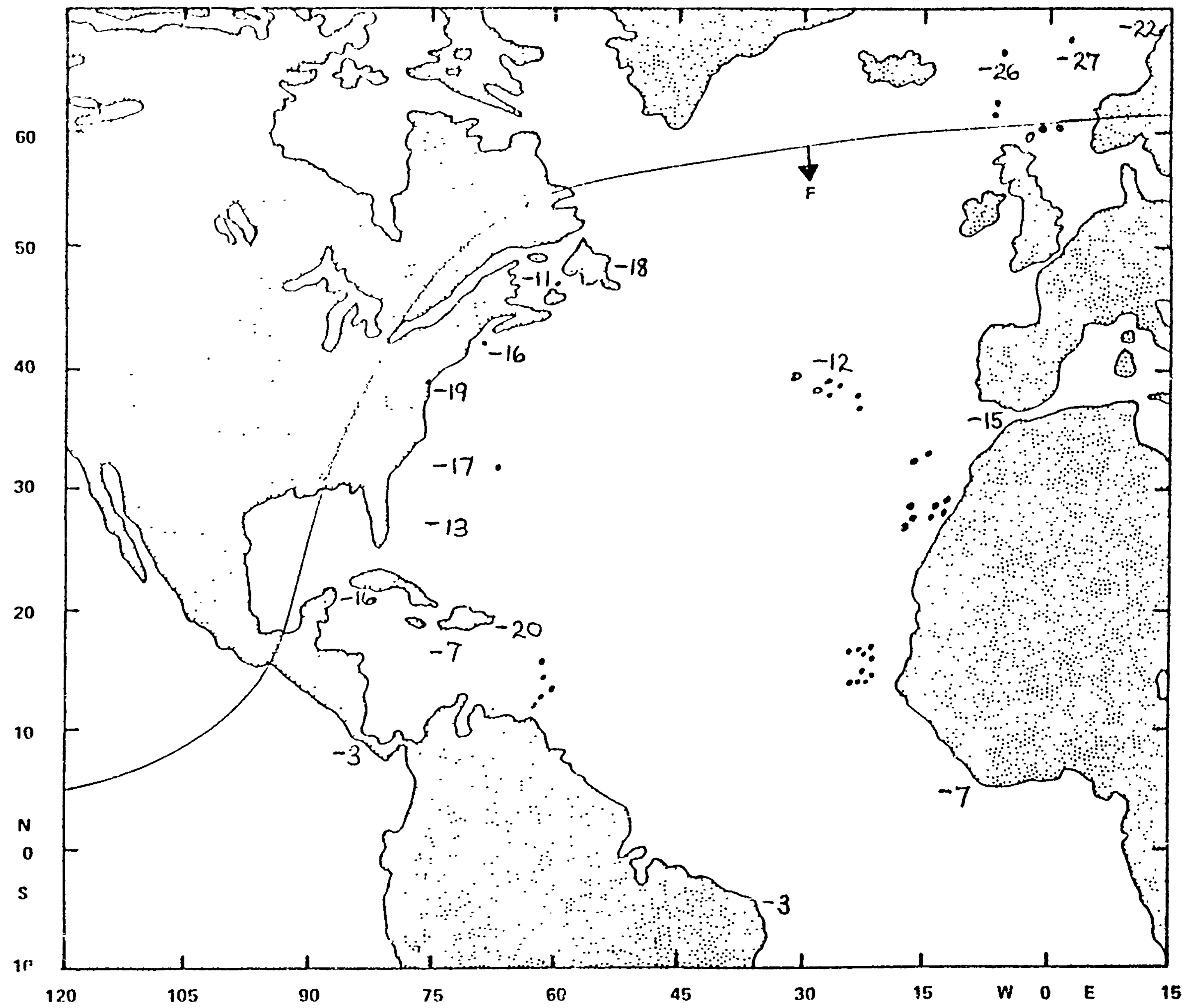

Figure C-21 OMEGA St. .on F Coverage - Summer Day

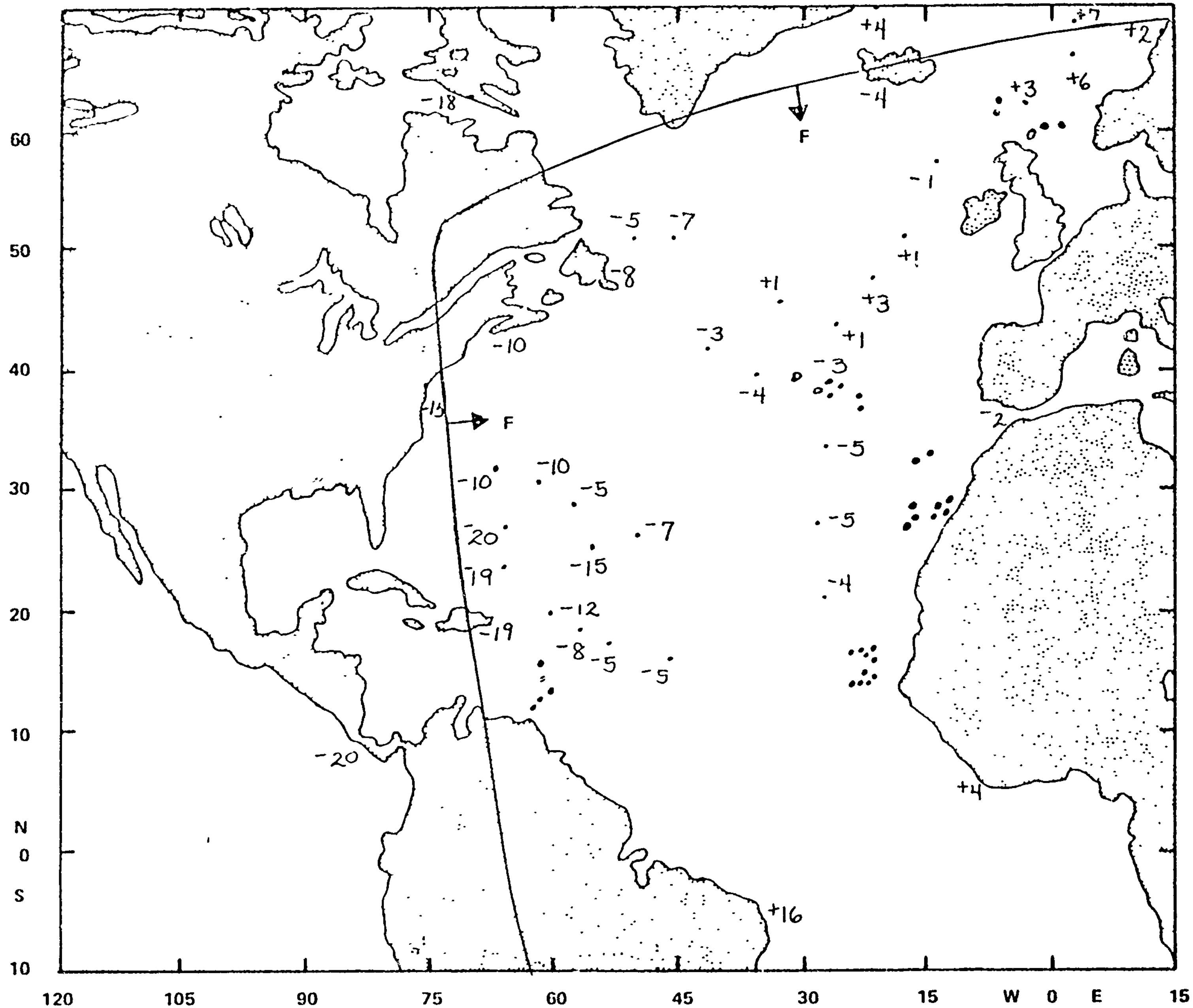

Figure C-22 OMEGA Station F Coverage - Summer Night

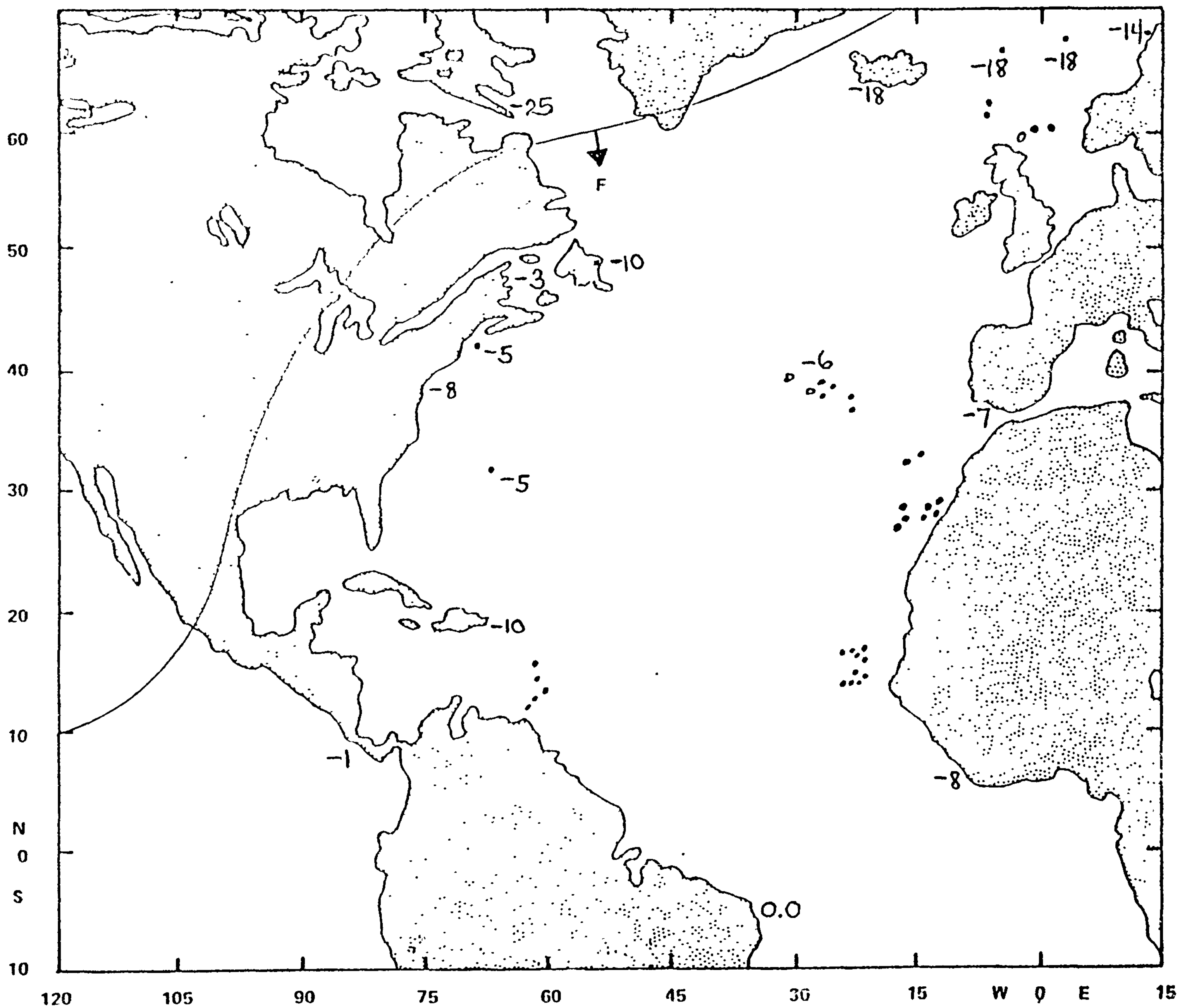

Figure C-23 OMEGA St on F Coverage - Winter Day

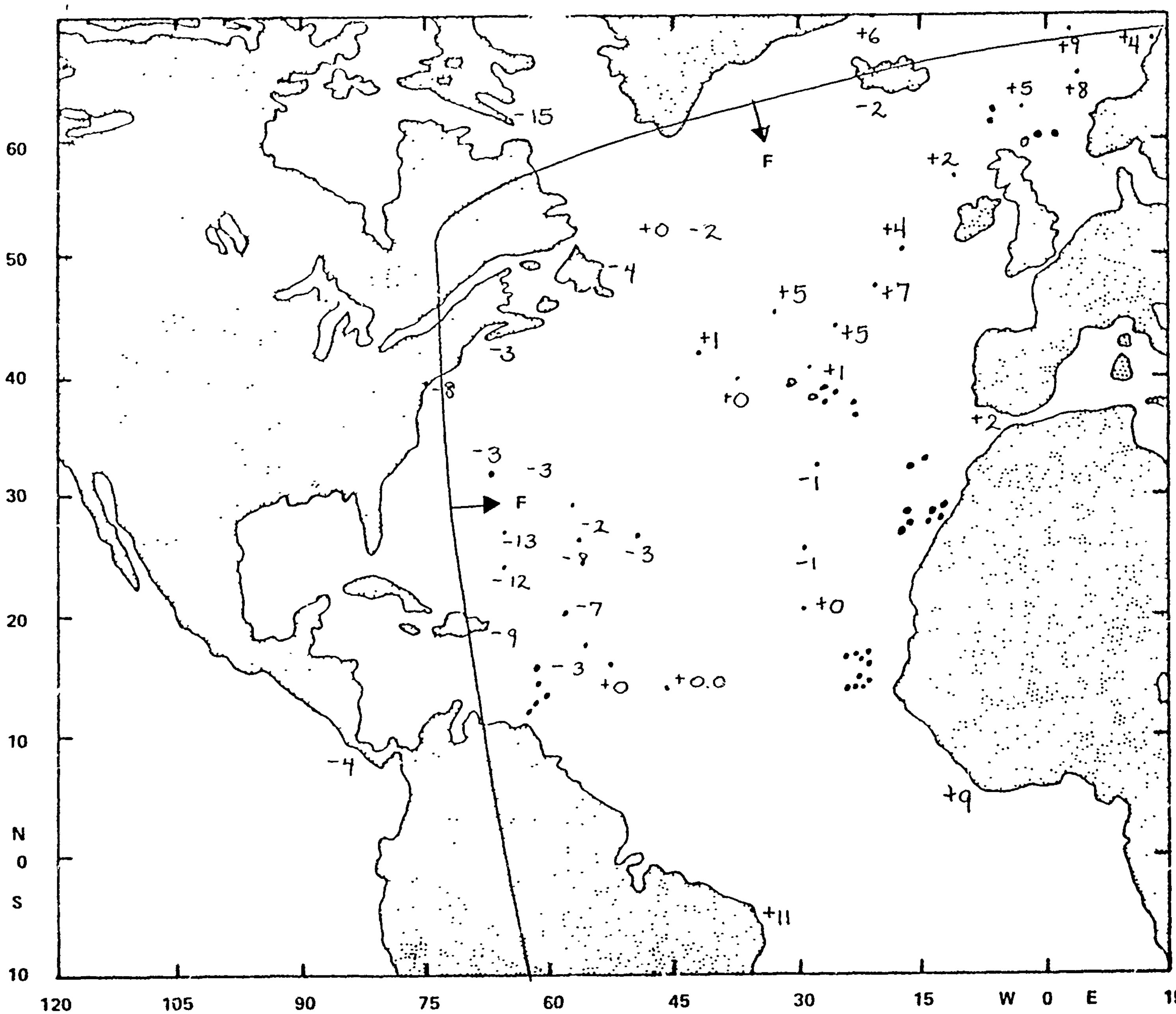

Figure C-24 OMEGA Station F Coverage - Winter Night

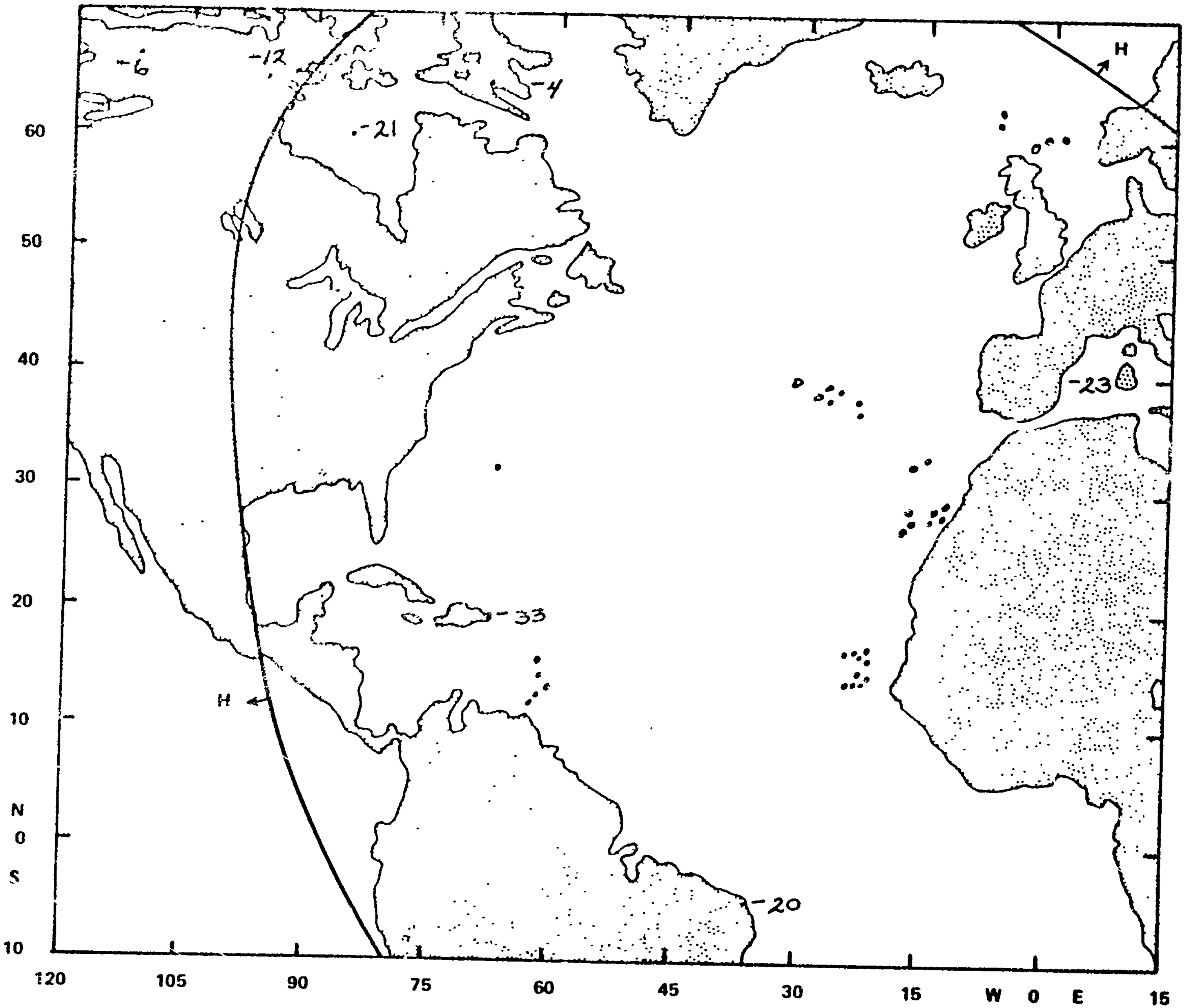

Figure C-25 OMEGA Station H Coverage - Summer Day

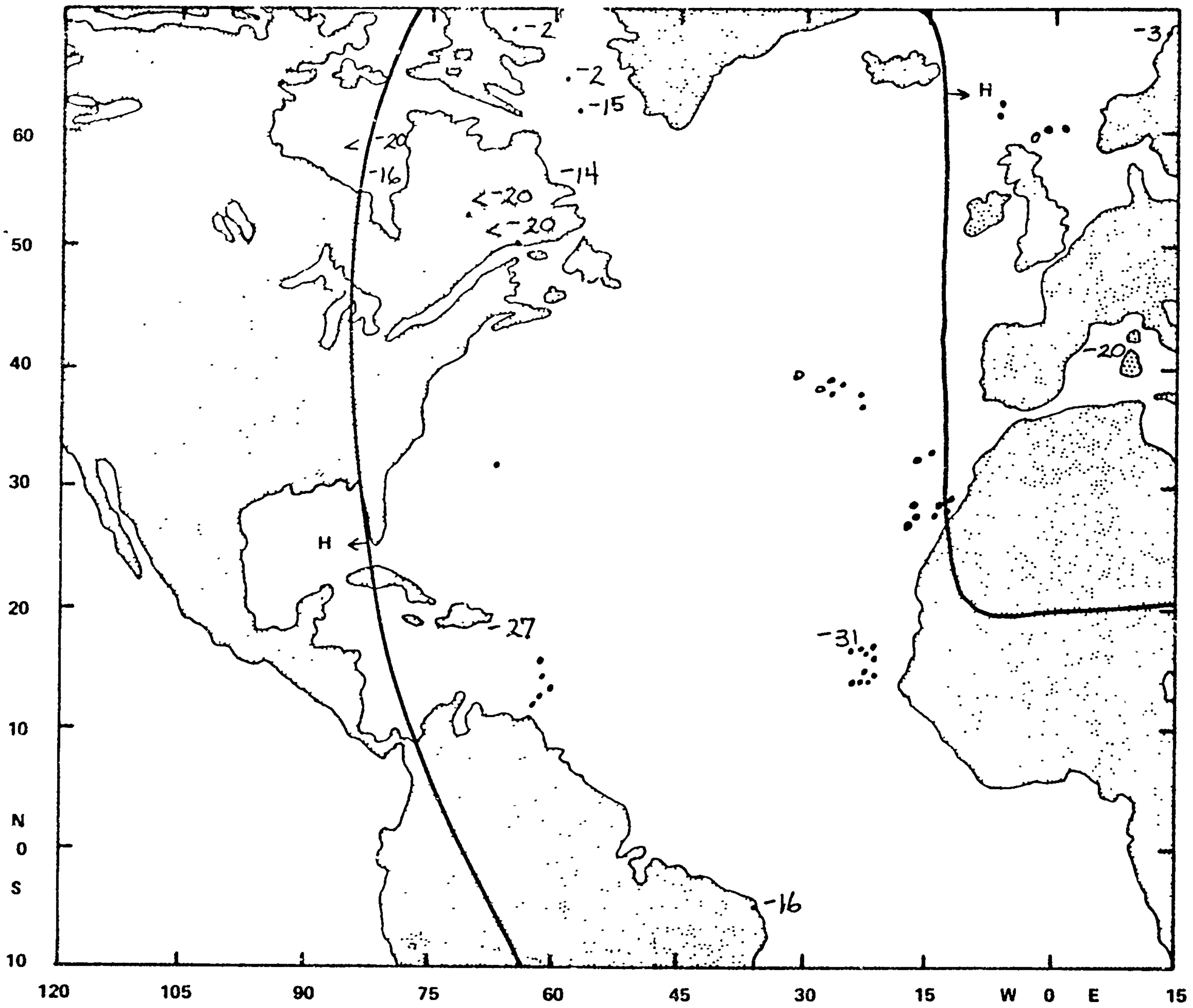

Figure C-26 OMEGA Station H Coverage - Summer Night

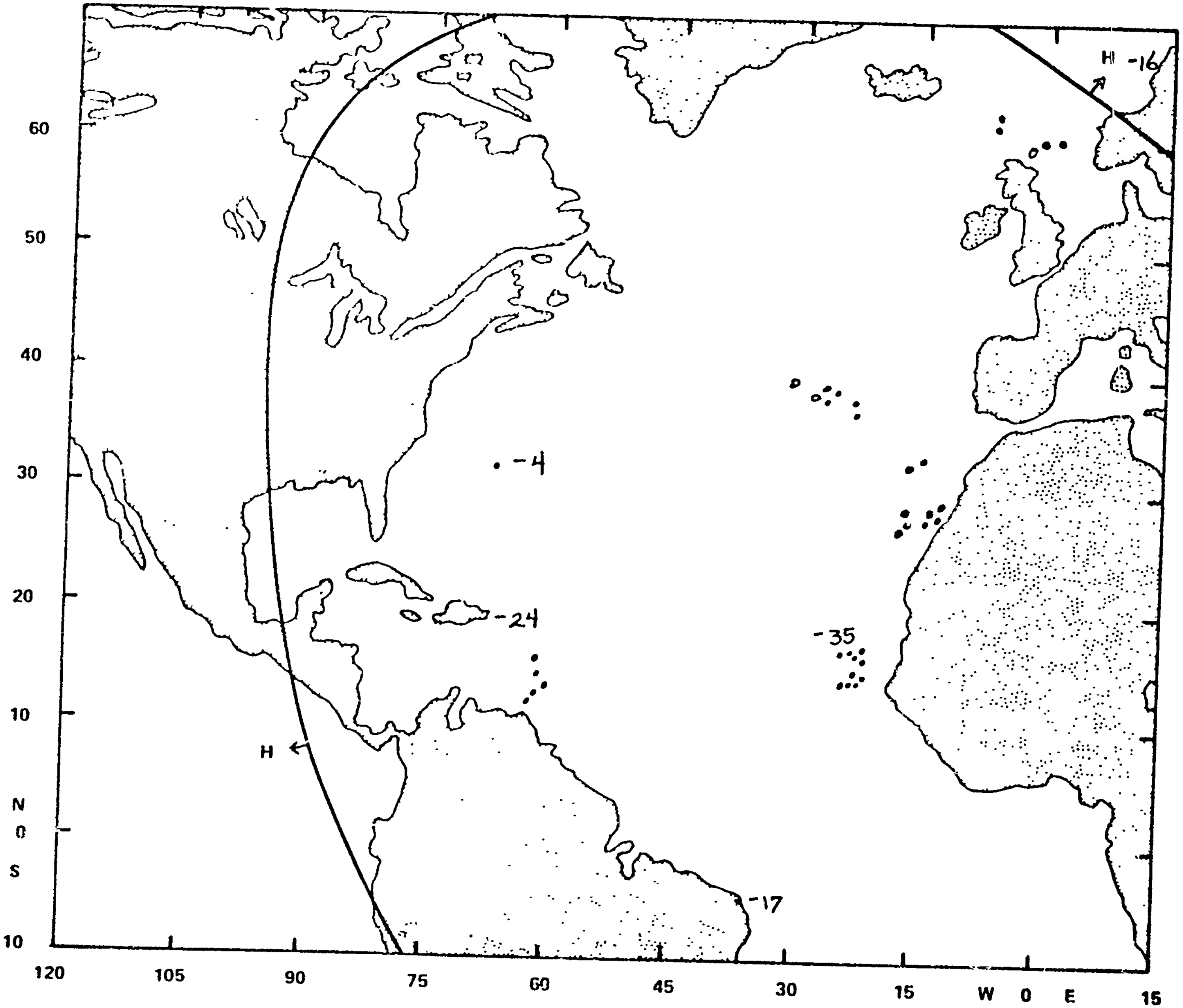

Figure C-27 OMEGA S ion H Coverage - Winter Day

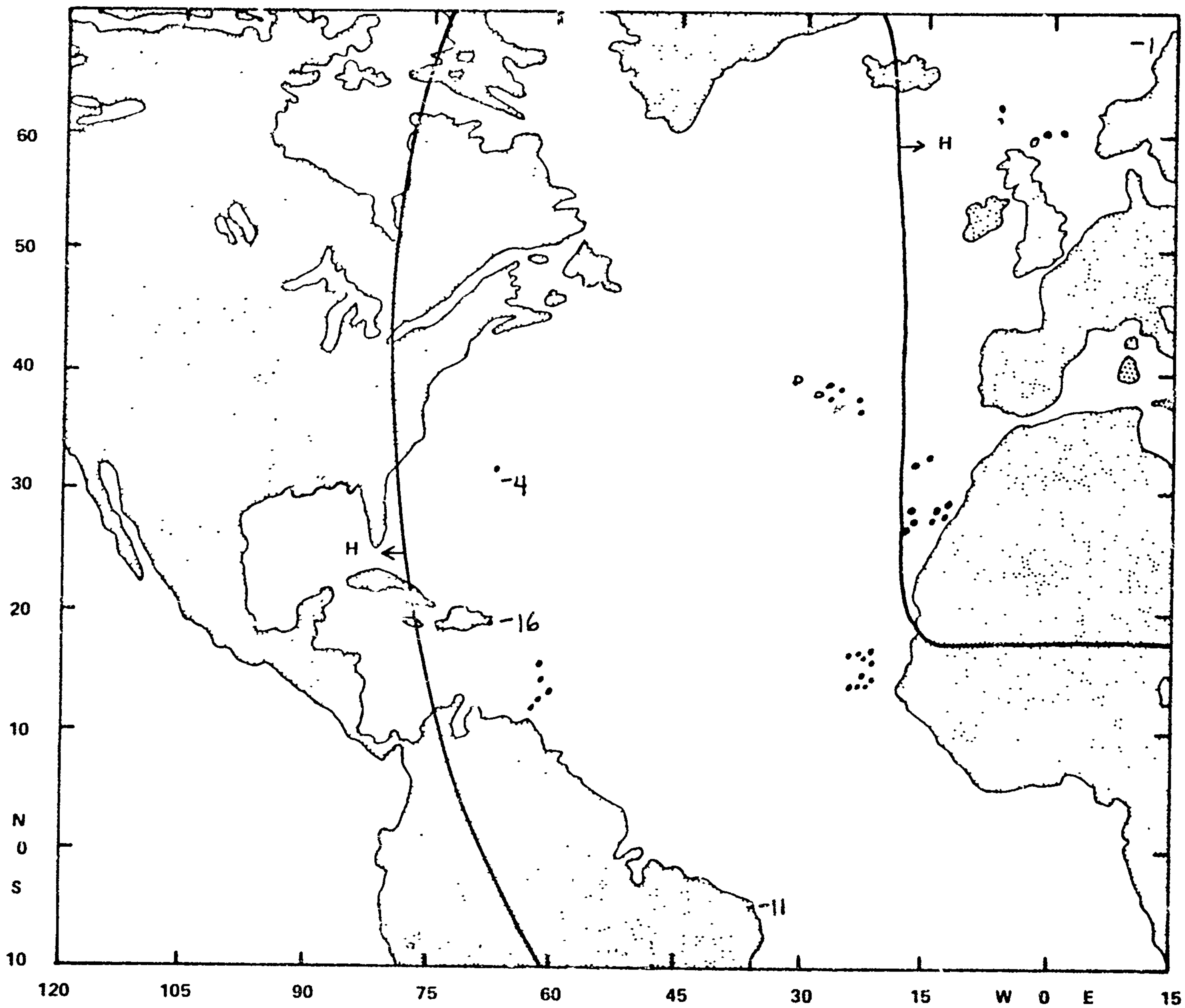

Figure C-28 OMEGA Station H Coverage -- Winter Night

APPENDIX D

Fix Accuracy Statistics

Included in this Appendix are tables of 10.2 kHz accuracy statistics from data measured at the ONSOD ground monitoring facilities as follows:

D-27 Piarco, Trinidad - Summer

D-28 Piarco, Trinidad - Winter

D-29 Portsmouth, VA - Winter

D-30 Sabana Seca, P.R. - Summer

D-31 Sabana Seca, P.R. - Winter

D-32 St. Anthony, Nfld - Summer

D-33 St. Anthony, Nfld. - Winter

D-34 Vila Nova, Azores - Summer

D-35 Vila Nova, Azores - Winter

D-36 Washington, D.C. - Summer

D-37 Washington, D.C. - Winter

TABLE D-1

10.2 kHz OMEGA ACCURACY SUMMARY; BELEM, BRAZIL; SUMMER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AC/AD	10.3	1.2 (1)	10.4 (3)	8.3	4.4 (3)	9.4 (3)
AC/CD	7.9	1.4 (2)	8.4 (1)	8.3	3.6 (2)	6.4 (1)
AC/CD	8.6	1.2 (1)	8.7 (2)	6.3	3.2 (1)	7.1 (2)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-2

10.2 kHz OMEGA ACCURACY SUMMARY; BELEM, BRAZIL; WINTER

8646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AC/AD	10.4	2.8 (2)	10.8 (1)	8.2	4.1 (3)	9.2 (3)
AC/CD	11.5	2.4 (1)	11.7 (3)	6.5	3.9 (2)	7.6 (1)
AD/CD	11.2	2.4 (1)	11.5 (2)	7.1	3.0 (1)	7.7 (2)

R = FIX BIAS ERROR

σ_r = STANDARD DEVIATION OF RADIAL ERROR

D = TOTAL FIX ERROR

( ) = RANK

TABLE D-3

10.2 kHz OMEGA ACCURACY SUMMARY; BERMUDA; SUMMER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AC/AD	39.7	4.7 (13)	40.1 (15)			
AC/AF	5.9	0.3 (1)	5.9 (11)	0.6	0.5 (1)	0.8 (1)
AC/BC	5.8	0.6 (3)	5.8 (10)			
AC/BD	5.9	1.0 (4)	6.0 (12)			
AC/DF	3.5	1.0 (4)	3.6 (7)			
AD/AF	3.1	1.2 (6)	3.3 (6)			
AD/BC	6.0	2.6 (11)	6.5 (13)			
AD/BD	3.6	1.8 (10)	4.1 (9)			
AD/DF	3.3	1.6 (9)	3.7 (8)			
AF/BC	1.9	0.4 (2)	1.9 (2)			
AF/BD	2.5	0.6 (3)	2.6 (5)			
AF/DF	2.5	1.1 (5)	2.7 (4)			
BC/BD	6.2	3.0 (12)	6.9 (14)			
BC/DF	0.7	1.3 (7)	1.5 (1)			
BD/DF	2.5	1.4 (8)	2.9 (5)			

R = FIX BIAS ERROR

σ_r = STANDARD DEVIATION OF RADIAL ERROR

D = TOTAL FIX ERROR

( ) = RANK

TABLE D-4

10.2 kHz OMEGA ACCURACY SUMMARY; BERMUDA; WINTER

5846

LOP PAIRS	DAYTIME R (nm)	DAYTIME σ_r (nm)	DAYTIME D (nm)	NIGHTTIME R (nm)	NIGHTTIME σ_r (nm)	NIGHTTIME D (nm)
AC/AD	5.8	3.1 (9)	6.6 (14)	27.5	3.3 (3)	27.7 (5)
AC/AF	0.8	0.9 (5)	1.2 (2)	6.1	0.7 (1)	6.1 (4)
AC/BC	4.0	0.9 (5)	4.1 (11)			
AC/BD	1.3	0.7 (3)	1.5 (3)			
AC/DF	3.2	0.8 (4)	3.3 (7)	3.4	0.7 (1)	3.5 (3)
AD/AF	0.7	0.8 (4)	1.1 (1)	2.8	0.7 (1)	2.9 (1)
AD/BC	3.5	1.3 (7)	3.8 (10)			
AD/BD	2.4	0.5 (1)	2.5 (6)			
AD/DF	3.3	0.7 (3)	3.4 (8)	3.2	0.8 (2)	3.3 (2)
AF/BC	1.9	0.7 (3)	2.1 (5)			
AF/BC	1.6	0.6 (2)	1.7 (4)			
AF/DF	5.5	1.0 (6)	5.6 (12)	2.8	0.8 (2)	2.9 (1)
BC/BD	19.5	1.9 (8)	19.6 (15)			
BC/DF	6.3	0.9 (5)	6.4 (13)			
BD/DF	3.7	0.7 (3)	3.7 (9)			

R = FIX BIAS ERROR

σ_r = STANDARD DEVIATION OF RADIAL ERROR

D = TOTAL FIX ERROR

( ) = RANK

TABLE D-5

10.2 kHz OMEGA ACCURACY SUMMARY; CAMBRIDGE, MA; SUMMER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AC/AD	33.9	22.0 (3)	40.4 (3)			
AC/CF	0.6	1.7 (1)	1.8 (1)			
AD/CF	1.9	2.1 (2)	2.8 (2)			

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-6

10.2 kHz OMEGA ACCURACY SUMMARY; CAMBRIDGE, MA; WINTER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AC/AD	15.7	9.5 (5)	18.4 (6)	21.6	10.5 (6)	24.0 (5)
AC/AF	2.4	0.2 (1)	2.4 (4)	2.9	0.7 (1)	3.0 (4)
AC/CF	1.6	0.6 (2)	1.7 (1)	1.5	1.0 (3)	1.8 (1)
AD/AF	2.1	0.8 (3)	2.2 (3)	2.0	0.7 (1)	2.1 (2)
AD/CF	1.7	1.1 (4)	2.0 (2)	1.8	1.1 (4)	2.1 (2)
AF/CF	4.0	0.6 (2)	4.1 (5)	2.7	0.8 (2)	2.8 (3)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-7

10.2 kHz OMEGA ACCURACY SUMMARY; EGLIN AFB, FLA; SUMMER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AC/AD	7.6	4.3 (6)	8.7 (3)	2.1	3.7 (3)	4.2 (3)
AC/CD	3.1	3.1 (5)	9.7 (4)	2.2	2.7 (2)	3.5 (1)
AC/CF	3.7	1.2 (2)	3.9 (2)			
AD/CD	8.2	3.0 (4)	8.7 (3)	2.2	2.6 (1)	4.0 (2)
AD/CF	9.4	2.6 (3)	9.7 (4)			
CD/CF	1.0	0.7 (1)	1.2 (1)			

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-8

10.2 kHz OMEGA ACCURACY SUMMARY; EGLIN AFB, FLA; WINTER

5846

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AC/AD	7.8	3.2 (6)	8.4 (4)	2.7	2.7 (2)	3.8 (1)
AC/CD	9.6	2.5 (5)	10.0 (6)	3.0	2.5 (1)	3.9 (2)
AC/CF	2.3	1.0 (2)	2.5 (1)			
AD/CD	8.6	2.3 (4)	8.9 (5)	2.9	2.7 (2)	3.9 (2)
AD/CF	8.0	2.0 (3)	8.3 (3)			
CD/CF	2.4	0.8 (1)	2.6 (2)			

R = FIX BIAS ERROR

σ_r = STANDARD DEVIATION OF RADIAL ERROR

D = TOTAL FIX ERROR

( ) = RANK

TABLE D-9

10.2 kHz OMEGA ACCURACY SUMMARY; FARNBOROUGH, U.K.; SUMMER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AB/AD	1.5	0.5 (1)	1.6 (1)	1.4	0.5 (1)	1.5 (1)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-10

10.2 kHz OMEGA ACCURACY SUMMARY, FARNBOROUGH, U.K.; WINTER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AB/AD	2.6	0.8 (1)	2.7 (1)	1.9	0.6 (1)	2.0 (1)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-11

10.2 kHz OMEGA ACCURACY SUMMARY, FROBISHER, N.W.T.; WINTER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AC/BD	1.6	6.2 (3)	6.4 (3)	5.3	5.6 (1)	7.7 (1)
AC/DF	2.7	3.4 (1)	4.3 (1)			
BD/DF	4.5	3.9 (2)	5.9 (2)			

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-12

10.2 kHz OMEGA ACCURACY SUMMARY; HESTMONA; SUMMER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
BC/BE	1.8	0.4 (1)	1.8 (6)	3.1	0.8 (3)	3.2 (7)
BC/BH	1.4	0.6 (3)	1.5 (3)	0.6	0.7 (2)	0.9 (2)
BC/CE	1.7	0.5 (2)	1.8 (6)	1.0	0.9 (4)	1.4 (5)
BC/CH	1.4	0.6 (3)	1.5 (3)	0.6	0.6 (1)	0.8 (1)
BC/EH	11.6	11.7 (7)	16.5 (8)	13.3	19.4 (10	23.5 (10)
BE/BH	1.5	0.6 (3)	1.6 (4)	4.5	1.0 (5)	4.6 (8)
BE/CE	1.8	0.5 (2)	1.8 (6)	2.9	1.0 (5)	3.1 (6)
BE/CH	2.9	1.3 (6)	3.1 (7)	5.6	2.0 (9)	5.9 (9)
BE/EH	1.6	0.5 (2)	1.7 (5)	2.9	1.2 (7)	3.1 (6)
BH/CH	1.4	0.6 (3)	1.2 (1)	0.6	0.7 (2)	0.9 (2)
BH/CE	1.4	0.5 (2)	1.5 (3)	0.5	0.7 (2)	0.9 (2)
BH/EH	1.4	0.7 (4)	1.6 (4)	0.8	1.2 (7)	1.4 (5)
CE/CH	0.9	0.8 (5)	1.2 (1)	0.2	1.1 (6)	1.1 (3)
CE/EH	1.0	0.8 (5)	1.3 (2)	0.1	1.4 (8)	1.4 (5)
CH/EH	1.0	0.8 (5)	1.2 (1)	0.2	1.1 (6)	1.2 (4)

R = FIX BIAS ERROR

σ_r = STANDARD DEVIATION OF RADIAL ERROR

D = TOTAL FIX ERROR

( ) = RANK

TABLE D-13

10.2 kHz OMEGA ACCURACY SUMMARY; HESTMONA; WINTER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
BC/BE	2.9	0.7 (1)	3.0 (5)	5.7	1.3 (4)	5.9 (9)
BC/BH	3.2	1.3 (4)	3.5 (7)	0.5	1.1 (2)	1.2 (1)
BC/CE	1.7	1.0 (2)	1.9 (2)	3.5	1.5 (5)	3.8 (5)
BC/CH	3.7	1.3 (4)	3.9 (8)	1.6	1.0 (1)	1.9 (2)
BE/BH	2.8	1.3 (4)	3.1 (6)	7.6	1.7 (7)	7.8 (12)
BE/CE	1.0	0.7 (1)	2.2 (3)	5.6	1.7 (7)	5.8 (8)
BE/CH	4.4	2.9 (8)	5.2 (12)	14.9	3.5 (11)	15.4 (13)
BE/EH	2.3	1.2 (3)	2.6 (4)	7.2	1.8 (8)	7.4 (11)
BH/CE	1.3	1.0 (2)	1.6 (1)	2.1	1.2 (3)	2.4 (4)
BH/CH	3.7	1.5 (5)	4.0 (9)	1.9	1.1 (2)	2.2 (3)
BH/EH	3.1	1.7 (7)	3.5 (7)	6.5	1.6 (6)	6.7 (10)
CE/CH	4.1	1.6 (6)	4.4 (10)	4.4	1.9 (9)	4.8 (7)
CE/EH	5.4	1.5 (5)	5.6 (13)	3.8	2.2 (10)	4.4 (6)
CH/EH	4.5	1.7 (7)	4.8 (11)	4.1	1.6 (6)	4.4 (6)

R = FIX BIAS ERROR

σ_r = STANDARD DEVIATION OF RADIAL ERROR

D = TOTAL FIX ERROR

( ) = RANK

TABLE D-14

10.2 kHz OMEGA ACCURACY SUMMARY; KEFLAVIK; SUMMER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AB/AD	1.6	0.2 (1)	1.6 (1)	1.0	0.4 (1)	1.1 (2)
AB/BD	1.6	0.3 (2)	1.6 (1)	0.9	0.5 (2)	1.0 (1)
AB/BF				8.8	0.8 (3)	8.8 (3)
AD/BD	1.6		1.6 (1)	0.9	0.5 (2)	1.1 (2)
AD/BF			11.1 (4)	36.2	2.7 (5)	36.3 (5)
BD/BF				15.5	1.4 (4)	15.6 (4)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-15

10.2 kHz OMEGA ACCURACY SUMMARY; KEFLAVIK; WINTER

5646

LOP PAIRS	DAYTIME R (nm)	DAYTIME σ_r (nm)	DAYTIME D (nm)	NIGHTTIME R (nm)	NIGHTTIME σ_r (nm)	NIGHTTIME D (nm)
AB/AD	1.7	0.7 (2)	1.8 (2)	0.5	0.8 (2)	0.9 (1)
AB/BD	1.7	0.5 (1)	1.8 (2)	0.7	0.7 (1)	1.0 (2)
AB/BF	4.3	0.7 (2)	4.3 (5)			
AB/DF	2.1	0.9 (4)	2.1 (4)	7.0	0.9 (3)	7.1 (4)
AD/BD	1.8	0.7 (2)	1.9 (3)	0.5	0.9 (3)	1.0 (2)
AD/DF	0.4	0.8 (3)	0.9 (1)	5.8	1.0 (4)	5.9 (3)
BD/BF	4.3	1.1 (5)	4.4 (6)			
BD/DF	4.4	1.4 (6)	4.6 (7)	14.7	1.7 (5)	14.8 (5)
BF/DF	4.3	1.1 (5)	4.4 (6)			

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-16

10.2 kHz OMEGA ACCURACY SUMMARY; LAJES, AZORES; SUMMER

5646

LOP PAIRS	DAYTIME R (nm)	DAYTIME σ_r (nm)	DAYTIME D (nm)	NIGHTTIME R (nm)	NIGHTTIME σ_r (nm)	NIGHTTIME D (nm)
AB/AC				3.3	0.8 (3)	3.4 (2)
AB/AD	0.5	0.2 (1)	0.5 (1)	1.3	0.6 (1)	1.4 (1)
AP/CF				17.2	4.6 (5)	17.8 (5)
AC/AD				25.8	5.9 (6)	26.5 (6)
AC/CF				4.8	0.9 (4)	4.9 (4)
AD/CF	0.3	1.0 (2)	1.0 (2)	3.6	0.7 (2)	3.7 (3)

R = FIX BIAS ERROR

σ_r = STANDARD DEVIATION OF RADIAL ERROR

D = TOTAL FIX ERROR

( ) = RANK

TABLE D-17

10.2 kHz OMEGA ACCURACY SUMMARY, LAJES, AZORES; WINTER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AB/AC	1.9	0.9 (2)	2.7 (4)	3.0	1.1 (3)	3.2 (3)
AB/AD	0.4	0.8 (1)	0.9 (1)	2.2	0.9 (1)	2.4 (2)
AB/CF	11.3	4.8 (3)	12.3 (5)	2.3	6.3 (4)	6.7 (4)
AC/AD	16.9	9.4 (4)	19.3 (6)	15.6	7.7 (5)	17.4 (5)
AC/CF	2.5	0.8 (1)	2.6 (3)	3.1	1.0 (2)	3.2 (3)
AD/CF	1.7	0.8 (1)	1.8 (2)	1.9	0.9 (1)	2.1 (1)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-18

10.2 kHz OMEGA ACCURACY SUMMARY; LA MOURE, N.D.; SUMMER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
CF/CH	0.5	0.6 (1)	0.8 (2)			
CF/FH	0.2	0.6 (1)	0.6 (1)			
CH/FH	0.5	0.7 (2)	0.8 (2)			

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

ƁLE D-19

10.2 kHz OMEGA ACCURACY SUMMARY, LA MOURE, N.D.; WINTER

5848

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
CF/CH	4.8	1.5 (1)	5.0 (1)			
CF/FH	4.8	1.6 (2)	5.1 (2)			
CH/FH	4.7	2.1 (3)	5.2 (3)			

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-20

10.2 kHz OMEGA ACCURACY SUMMARY; MONROVIA, LIBERIA; SUMMER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AE/AF	2.3	0.3 (1)	2.3 (1)	2.9	1.0 (1)	3.1 (1)
AE/LF	2.3	0.3 (1)	2.3 (1)	2.9	1.2 (2)	3.2 (2)
AF/EF	2.3	0.3 (1)	2.3 (1)	2.9	1.0 (1)	3.1 (1)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-21

10.2 kHz OMEGA ACCURACY SUMMARY; MONROVIA, LIBERIA; WINTER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AE/AF	1.5	0.5 (2)	1.6 (1)	1.3	0.9 (2)	1.6 (2)
AE/EF	1.6	0.4 (1)	1.7 (2)	1.3	0.9 (2)	1.6 (2)
AF/EF	1.9	0 4 (1)	2.0 (3)	1.3	0.8 (1)	1.5 (1)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-22

10.2 kHz OMEGA ACCURACY SUMMARY, NATAL, BRAZIL; WINTER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AD/AE				4.8	1.8 (4)	5.1 (5)
AD/BF	2.6	2.6 (3)	3.7 (3)	5.4	3.3 (8)	6.3 (7)
AD/CD	7.8	6.7 (5)	10.2 (5)	4.7	4.9 (9)	6.8 (8)
AD/DF	0.5	1.6 (2)	1.7 (2)	4.7	1.5 (3)	5.0 (4)
AD/EF				39.5	14.3 (11)	42.0 (10)
AE/CD				4.4	2.4 (6)	5.0 (4)
AE/DF				2.8	2.2 (5)	3.5 (3)
AE/EF				1.3	1.3 (2)	1.9 (2)
BF/CD	33.2	14.9 (6)	36.4 (6)			
BF/DF	1.1	0.7 (1)	1.3 (1)			
CD/DF	9.0	4.4 (4)	10.1 (4)	5.0	2.5 (7)	5.6 (6)
CD/EF				7.4	5.3 (10)	9.1 (9)
DF/EF				1.1	1.2 (1)	1.6 (1)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

ABLE D-23

10.2 kHz OMEGA ACCURACY SUMMARY; NEA MAKRI, GREECE; SUMMER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AB/AE	1.6	0.1 (1)	1.6 (5)			
AB/BH	0.5	0.4 (4)	0.6 (1)	1.8	0.6 (1)	2.0 (1)
AE/AF	0.9	0.2 (2)	0.9 (2)			
AE/BH	0.9	0.3 (3)	1.0 (3)			
AF/BH	1.3	0.6 (5)	1.5 (4)	5.6	0.8 (2)	5.7 (2)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-24

10.2 kHz OMEGA ACCURACY SUMMARY; NEA MAKRI, GREECE; WINTER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AB/AE	1.2	0.6 (2)	1.3 (4)			
AB/BH	1.1	0.6 (2)	1.3 (4)	2.0	0.8 (2)	2.1 (1)
AE/AF	0.5	0.7 (3)	0.8 (2)			
AE/BH	0.3	0.5 (1)	0.6 (1)			
AF/BH	0.2	0.9 (4)	1.0 (3)	3.1	0.7 (1)	3.2 (2)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-25

10.2 kHz OMEGA ACCURACY SUMMARY; PANAMA; SUMMER

5646

LOP PAIRS	DAYTIME R (nm)	DAYTIME σ_r (nm)	DAYTIME D (nm)	NIGHTTIME R (nm)	NIGHTTIME σ_r (nm)	NIGHTTIME D (nm)
AD/BD	3.2	0.9 (3)	3.3 (5)			
AD/CD	2.5	0.9 (3)	2.7 (3)	4.1	1.5 (1)	4.3 (1)
AD/CF	2.1	0.7 (2)	2.2 (1)			
BD/CD	2.7	0.4 (1)	2.7 (3)			
BD/CF	2.1	1.1 (4)	2.4 (2)			
CD/CF	2.8	0.4 (1)	2.9 (4)			

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-26

10.2 kHz OMEGA ACCURACY SUMMARY; PANAMA; WINTER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AD/CD				4.5	2.1 (1)	5.0 (1)
AD/CF						
CD/CF						

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-27

10.2 kHz OMEGA ACCURACY SUMMARY, PIARCO, TRINIDAD; SUMMER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AC/AD	3.5	1.2 (4)	3.8 (4)	4.7	2.0 (3)	5.1 (2)
AC/BD	2.1	0.4 (1)	2.1 (2)			
AC/CD	3.7	1.2 (4)	3.9 (5)	4.7	1.9 (2)	5.1 (2)
AD/BD	1.2	0.5 (2)	1.3 (1)			
AD/CD	3.7	1.1 (3)	3.8 (4)	4.7	1.6 (1)	5.0 (1)
BD/CD	3.0	0.5 (2)	3.1 (3)			

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-28

10.2 kHz OMEGA ACCURACY SUMMARY; PIARCO, TRINIDAD; WINTER

5846

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
BD/CD	6.5	0.9 (1)	6.5 (1)			

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-29

10.2 kHz OMEGA ACCURACY SUMMARY; PORTSMOUTH, VA.; WINTER

5646

LOP PAIRS	DAYTIME R (nm)	DAYTIME σ_r (nm)	DAYTIME D (nm)	NIGHTTIME R (nm)	NIGHTTIME σ_r (nm)	NIGHTTIME D (nm)
AB/AC	3.4	1.1 (2)	3.6 (3)			
AB/AD	3.5	1.4 (3)	3.8 (4)			
AB/CD	3.3	3.0 (5)	4.4 (5)			
AC/AD	2.8	4.1 (8)	4.9 (7)	4.8	5.0 (6)	6.9 (3)
AC/CD	3.1	3.6 (6)	4.7 (6)	5.7	4.5 (5)	7.3 (5)
AC/DF	1.7	0.9 (1)	1.9 (2)	3.0	1.0 (1)	3.2 (1)
AD/CD	3.1	3.9 (7)	4.9 (8)	5.6	4.3 (4)	7.1 (4)
AD/DF	1.2	1.1 (2)	1.6 (1)	3.5	1.1 (2)	3.7 (2)
CD/DF	4.2	2.8 (4)	5.1 (9)	7.6	2.9 (3)	8.1 (6)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-30

10.2 kHz OMEGA ACCURACY SUMMARY; SABANA SECA, P.R.; SUMMER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AC/AF	0.8	0.4 (2)	0.9 (2)	4.7	0.5 (1)	4.7 (3)
AC/CD	3.2	1.1 (4)	3.4 (5)	5.2	1.6 (5)	5.4 (4)
AC/DF	0.9	0.3 (1)	1.0 (3)	3.3	0.6 (2)	3.3 (1)
AF/CD	4.8	1.6 (5)	5.1 (6)	15.8	2.0 (6)	15.4 (6)
AF/DF	0.5	0.4 (2)	0.7 (1)	3.5	0.7 (3)	3.5 (2)
CD/DF	2.5	0.6 (3)	2.6 (4)	6.8	1.2 (4)	6.9 (5)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-31

10.2 kHz OMEGA ACCURACY SUMMARY; SABANA SECA, P.R.; WINTER

5646

LOP PAIRS	DAYTIME R (nm)	DAYTIME σ_r (nm)	DAYTIME D (nm)	NIGHTTIME R (nm)	NIGHTTIME σ_r (nm)	NIGHTTIME D (nm)
AC/AD	5.4	3.6 (10)	6.4 (10)	7.4	2.7 (6)	7.9 (6)
AC/AF	3.7	1.[illegible] ([illegible])	3.9 (7)	4.9	0.9 (2)	5.0 (4)
AC/BD	4.9	[illegible]	4.9 (9)			
AC/CD	7.7	2.[illegible]	8.2 (13)	3.5	2.4 (5)	4.2 (3)
AC/DF	3.7	0.7 (2)	3.7 (6)	3.1	0.8 (1)	3.2 (1)
AD/AF	2.5	1.4 (7)	2.8 (5)	3.2	0.9 (2)	3.3 (2)
AD/BD	4.5	1.4 (7)	4.7 (8)			
AD/CD	7.2	3.1 (9)	7.8 (12)	4.6	2.2 (4)	5.1 (5)
AD/DF	2.6	1.0 (5)	2.7 (4)	3.1	0.9 (2)	3.2 (1)
AF/BD	1.4	0.8 (3)	1.5 (2)			
AF/CD	12.7	4.6 (11)	13.5 (14)	13.3	3.0 (6)	18.5 (8)
AF/DF	2.1	1.0 (5)	2.3 (3)	3.2	0.9 (2)	3.3 (2)
BD/CD	6.7	1.0 (5)	6.8 (11)			
BD/DF	0.3	0.3 (1)	0.4 (1)			
CD/DF	7.7	1.1 (6)	7.8 (12)	8.0	1.3 (3)	8.2 (7)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-32

10.2 kHz OMEGA ACCUPACY SUMMARY, ST. ANTHONY, NFLD; SUMMER

5646

LOP PAIRS	DAYTIME R (nm)	DAYTIME σ_r (nm)	DAYTIME D (nm)	NIGHTTIME R (nm)	NIGHTTIME σ_r (nm)	NIGHTTIME D (nm)
AB/AC	0.1	1.3 (3)	1.3 (2)			
AB/AD	0.6	0.5 (1)	0.7 (1)			
AB/CF	1.0	3.7 (5)	3.8 (4)			
A[illegible]/AD	3.4	5.7 (6)	6.7 (5)	1.0	4.2 (3)	4.3 (3)
AC/CF	0.3	1.6 (4)	1.6 (3)	3.8	1.2 (2)	4.0 (2)
AD/CF	0.6	1.2 (2)	1.3 (2)	3.7	1.0 (1)	3.8 (1)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-33

10.2 kHz OMEGA ACCURACY SUMMARY; ST. ANTHONY, NFLD.; WINTER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AC/AD				4.5	3.4 (2)	5.7 (2)
A[illegible]/[illegible]F				4.1	0.7 (1)	4.1 (1)
AD/[illegible]F				4.1	0.7 (1)	4.1 (1)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-34

10.2 kHz OMEGA ACCURACY SUMMARY; VILA NOVA, AZORES; SUMMER

5846

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AB/AF	2.0	0.4 (2)	2.0 (4)	8.4	0.9 (3)	8.4 (4)
AB/BD	0.7	0.3 (1)	0.7 (1)	1.5	0.8 (2)	1.7 (1)
AB/DF	3.5	1.3 (4)	3.7 (6)	23.3	2.8 (5)	23.5 (6)
AF/BD	1.1	0.3 (1)	1.2 (3)	3.1	0.6 (1)	3.2 (2)
AF/DF	0.6	0.4 (2)	0.8 (2)	4.3	0.8 (2)	4.3 (3)
BD/DF	2.4	0.5 (3)	2.4 (5)	10.1	1.1 (4)	10.2 (5)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-35

10.2 kHz OMEGA ACCURACY SUMMARY; VILA NOVA, AZORES; WINTER

5346

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AB/AD	0.9	0.6 (2)	1.1 (2)	2.2	0.7 (1)	2.3 (1)
AB/BD	0.9	0.5 (1)	1.0 (1)	2.2	0.7 (1)	2.3 (1)
AD/BD	0.9	0.7 (3)	1.1 (2)	2.2	C.8 (2)	2.3 (1)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-36

10.2 kHz OMEGA ACCURACY SUMMARY, WASHINGTON, D.C.; SUMMER

5646

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AB/AC	0.4	0.5 (2)	0.8 (2)			
AB/AD	0.3	0.6 (2)	0.7 (1)			
AB/CD	2.1	1.6 (5)	2.7 (7)			
AB/DF	3.3	3.4 (7)	4.8 (9)			
AC/AD	2.9	1.9 (6)	3.5 (8)	3.3	2.4 (4)	4.1 (5)
AC/CD	1.7	1.5 (4)	2.3 (4)	3.3	2.2 (3)	4.0 (4)
AC/DF	0.7	0.4 (1)	0.8 (2)	0.5	1.1 (1)	1.2 (1)
AD/CD	1.9	1.5 (4)	2.4 (5)	3.3	2.0 (2)	3.9 (3)
AD/DF	0.8	0.4 (1)	0.9 (3)	0.8	1.1 (1)	1.4 (2)
CD/DF	2.3	0.9 (3)	2.5 (6)	2.4	4.1 (5)	4.7 (6)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK

TABLE D-37

10.2 kHz OMEGA ACCURACY SUMMARY; WASHINGTON, D.C.; WINTER

5846

LOP PAIRS	DAYTIME			NIGHTTIME		
	R (nm)	σ_r (nm)	D (nm)	R (nm)	σ_r (nm)	D (nm)
AB/AC	1.4	1.4 (3)	2.0 (4)			
AB/AD	0.6	1.5 (4)	1.6 (3)			
AB/CD	8.6	4.0 (7)	9.5 (9)			
AB/DF	6.1	7.4 (9)	9.6 (10)			
AC/AD	6.4	4.8 (8)	8.1 (5)	4.6	4.6 (4)	6.5 (6)
AC/CD	8.5	4.0 (7)	9.4 (8)	4.4	4.0 (3)	6.0 (5)
AC/DF	1.3	0.9 (2)	1.5 (2)	0.7	1.4 (1)	1.6 (1)
AD/CD	8.2	3.7 (6)	9.0 (7)	4.5	3.6 (2)	5.7 (4)
AD/DF	0.3	0.8 (1)	0.9 (1)	1.4	1.4 (1)	2.0 (2)
CD/DF	8.4	2.0 (5)	8.6 (6)	2.9	4.8 (5)	5.6 (3)

R = FIX BIAS ERROR
σ_r = STANDARD DEVIATION OF RADIAL ERROR
D = TOTAL FIX ERROR
( ) = RANK